Volume 28 NOVEMBER, 1944 Number 11

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

Problems of Underground Gas Storage, Ohio, West Virginia, and Pennsylvania *By F. H. Finn, J. J. Schmidt, and J. B. Corrin, Jr.* 1561

Upper Permian Ochoa Series of Delaware Basin, West Texas and Southeastern New Mexico *By John Emery Adams* 1596

Moorefield Formation and Ruddell Shale, Batesville District, Arkansas *By Mackenzie Gordon, Jr.* 1626

Salt Diffusion in Woodbine Sand Waters, East Texas *By C. W. Horton* 1635

GEOLOGICAL NOTES

Fusulinids in La Quinta Formation, Venezuela *By H. P. Schaub* 1642

Ammonoids from Upper Cherry Canyon of Delaware Mountain Group in Texas *By R. L. Clifton* 1644

South Tyler Field, Smith County, Texas *By T. E. Weirich* 1646

Sand Flat Field, Smith County, Texas *By L. D. Bartell* 1647

DISCUSSION

Classification of Faults, and Thrust Fault on Barranquilla-Cartagena Highway, Colombia *By Mason L. Hill and Stuart K. Clark* 1649

REVIEWS AND NEW PUBLICATIONS

Air Photography and Geology, by R. W. Willett *By Burton Wallace Collins* 1652

Progress Reports on Geology of Alaska Highway, by Geological Survey of Canada *By J. V. Howell* 1655

Historical Geology, by Russell C. Hussey *By W. A. Ver Wiebe* 1657

Recent Publications 1658

THE ASSOCIATION ROUND TABLE

Association Committees 1661

Membership Applications Approved for Publication 1663

30th Annual Meeting, Tulsa, March 20-22, 1945 1665

Geology of Barco Concession, Colombia—Reprints 1665

MEMORIAL

Lee Hager *By Alexander Deussen* 1666

Jesse Homer Derden *By C. W. Roop* 1668

AT HOME AND ABROAD

Current News and Personal Items of the Profession 1670

Copyright, 1944, by The American Association of Petroleum Geologists, Inc.

IN VENEZUELA AND COLOMBIA

A

COMPLETE EXPLORATION SERVICE

★

100% Seismograph Operations

Gamma Ray and Neutron Surveys

Well Logging by Mud Analysis.

Seismograph Service Corporation of Delaware

CONSULTING EXPLORATION GEOPHYSICISTS

Caracas, Venezuela — KENNEDY BUILDING — Bogotá, Colombia

TULSA, OKLAHOMA, U. S. A.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 708 WRIGHT BUILDING, TULSA, OKLAHOMA

GAYLE SCOTT, *Editor*

TEXAS CHRISTIAN UNIVERSITY, FORT WORTH 9, TEXAS

ASSOCIATE EDITORS

GENERAL	K. C. HEALD, Gulf Oil Corporation, Box 1166, Pittsburgh 30, Pa. HUGH D. MISER, U. S. Geological Survey, Washington 25, D. C. THERON WASSON, Pure Oil Company, 35 E. Wacker Drive, Chicago 1, Ill.
APPALACHIANS	
North	JOHN R. REEVES, Penn-York Natural Gas Corporation, Buffalo, N. Y.
NORTH CENTRAL STATES	R. B. NEWCOMBE, Superior Oil Company, Grand Rapids, Mich.
KANSAS	EDWARD A. KOESTER, Darby and Bothwell, Inc., Wichita 2, Kan.
OKLAHOMA	
Western	ROBERT H. DOTT, Oklahoma Geological Survey, Norman, Okla.
Eastern	SHERWOOD BUCKSTAFF, Shell Oil Company, Inc., Box 1191, Tulsa 2, Okla.
TEXAS	
North and Central	J. B. LOVEJOY, Gulf Oil Corporation, Fort Worth 1, Tex.
Northeastern	C. I. ALEXANDER, Magnolia Petroleum Company, Tyler, Tex.
San Antonio	JOHN R. SANDIDGE, Magnolia Petroleum Company, San Antonio 5, Tex.
Permian Basin	E. RUSSELL LLOYD, Box 1026, Midland, Tex.
GULF COAST	SIDNEY A. JUDSON, Texas Gulf Producing Company, Houston 1, Tex. MARCUS A. HANNA, Gulf Oil Corporation, Houston 1, Tex.
ARKANSAS AND NORTH LOUISIANA	ROY T. HAZZARD, Gulf Refining Company of Louisiana, Shreveport 93, La.
ROCKY MOUNTAINS	A. E. BRAINERD, Continental Oil Company, Denver 2, Colo.
CALIFORNIA	W. D. KLEINPELL, Box 1131, Bakersfield, Calif.
FOREIGN	
Canada	THEODORE A. LINK, Imperial Oil Limited, Toronto, Ontario
South America	HOLLIS D. HEDBERG, Mene Grande Oil Co., Apt. 45, Barcelona, Venezuela

THE BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS is published by the Association on the 15th of each month. Editorial and publication office, 708 Wright Building, Tulsa, Oklahoma, Post Office Box 979.

THE SUBSCRIPTION PRICE to non-members of the Association is $15.00 per year (separate numbers, $1.50) prepaid to addresses in the United States. For addresses outside the United States, an additional charge of $0.40 is made on each subscription to cover extra wrapping and handling.

British agent: Thomas Murby & Co., 40 Museum Street, London, W. C. I.

CLAIMS FOR NON-RECEIPT of preceding numbers of THE BULLETIN must be sent Association headquarters within three months of the date of publication in order to be filled gratis.

BACK NUMBERS OF THE BULLETIN, as available, can be ordered from Association headquarters. Cloth-bound Vols. 11 (1927) to 15 (1931), $6.00; Vols. 22 (1938) to 24 (1940) and Vols. 26 (1942) to 27 (1943), each $17.00. Separate numbers, and a few nearly complete sets are available. Descriptive price list sent on request. Special prices to members and associates. Discounts to libraries. *Geology of Natural Gas* (1935), $6.00 ($4.50 to members and associates). *Geology of Tampico Region, Mexico* (1936), $4.50 ($3.50 to members and associates). *Gulf Coast Oil Fields* (1936), $4.00 ($3.00 to members and associates). *Miocene Stratigraphy of California* (1938), $5.00 ($4.50 to members and associates). *Stratigraphic Type Oil Fields* (1941), $5.50 ($4.50 to members and associates). *Source Beds of Petroleum* (1942), $4.50 ($3.50 to members and associates). *Petroleum Discovery Methods* (1942), $1.00. *Possible Future Oil Provinces of the United States and Canada* (1941, reprinted 1944), $1.50 ($1.00 to members and associates).

THE BULLETIN gives senior authors 35 reprints of major papers. Additional reprints, in limited numbers, and for private distribution, are furnished at cost, if orders accompany corrected galley proof.

Association Headquarters—708 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma.

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

BOX 979

TULSA 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1923.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.

OFFICERS FOR THE YEAR ENDING MARCH, 1945

IRA H. CRAM, *President*, Chicago, Illinois
ROBERT E. RETTGER, *Secretary-Treasurer*, Dallas, Texas
WARREN B. WEEKS, *Vice-President*, Bartlesville, Okla.
GAYLE SCOTT, *Editor*, Fort Worth, Texas

The foregoing officers, together with the *Past-President*, A. RODGER DENISON, Tulsa, Oklahoma, constitute the Executive Committee.

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in parentheses)

Amarillo: Elisha A. Paschal (46), Amarillo, Tex.
Appalachian: M. Gordon Gulley (45), Pittsburgh, Pa.
Canada: J. G. Spratt (45), Calgary, Canada
Capital: Carle H. Dane (46), Washington, D. C.
Corpus Christi: Guy B. Gierhart (45), Corpus Christi, Tex.
Dallas: Barney Fisher (46), Dallas, Tex.
East Oklahoma: D. E. Lounsbery (46), Bartlesville, R. Clare Coffin (45), Lucian H. Walker (45), Tulsa
Fort Worth: Charles E. Yager (45), Fort Worth, Tex.
Great Lakes: Edwin G. Cole (45), Evansville, Ind.; Darsie A. Green (45), Olney, Ill.
Houston: S. G. Gray (45), W. B. Moore (45), George S. Buchanan (46), Donald M. Davis (46), Houston, Tex.
Michigan: Rex P. Grant (45), Lansing, Mich.
New Mexico: Robert L. Bates (45), Socorro, N. Mex.
New York: Lewis G. Weeks (45), New York City
Pacific Coast: Eugene H. Vallat (46), Robert T. White (46), Los Angeles, Calif.
Mason L. Hill (45), James C. Kimble (45), Bakersfield, Calif.
Rocky Mountains: Charles S. Lavington (45), Denver, Colo.
Shreveport: J. D. Aimer (45), Shreveport, La.
South America: Philip E. Nolan (45), Caracas, Venezuela
Southeast Gulf: Tom McGlothlin (45), Jackson, Miss.
Southern Louisiana: Gordon I. Atwater (45), New Orleans
So. Permian Basin: F. H. McGuigan (45), John M. Hills (46), Midland, Tex.
South Texas: Edwin L. Porch (46), San Antonio
Tyler: T. C. Cash (45), Tyler, Tex.
West Oklahoma: R. W. Camp (45), Oklahoma City, Okla.
Wichita: W. C. Imbt (45), Wichita, Kan.
Wichita Falls: Earl M. Stilley (46), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Paleontology and Mineralogy
Donald D. Hughes (45), Stanford University, California
Henryk B. Stenzel (45), Austin, Texas

PACIFIC SECTION (Chartered, March, 1925)

R. G. REESE, *President*, Standard Oil Company of California, Box 1200, Bakersfield, California
GLENN H. BOWES, *Vice-President*, Continental Oil Company, 601 W. 5th Street, Los Angeles, California
ROBERT T. WHITE, *Secretary-Treasurer*, Barnsdall Oil Company, Petroleum Building, Los Angeles, California
Membership restricted to members of the Association in good standing, residing in Pacific Coast states. Dues: $1.50 per year

SOUTH TEXAS SECTION (Chartered, April, 1929)

ROBERT N. KOLM, *President*, Atlantic Refining Co., 1742 Milam Building, San Antonio, Texas
ROBERT D. MEBANE, *Secretary-Treasurer*, Saltmount Oil Co., 916 Milam Building, San Antonio, Texas
Membership limited to persons eligible to Association membership. Dues: $2.50. Annual meeting in October.

DIVISION OF PALEONTOLOGY AND MINERALOGY
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)
DONALD D. HUGHES, *President*, Stanford University, California
HENRYK B. STENZEL, *Secretary-Treasurer*, Bureau of Economic Geology, Austin, 12, Texas

SEND DUES, SUBSCRIPTIONS AND ORDERS FOR BACK NUMBERS TO BOX 979, TULSA, 1, OKLAHOMA. The Society and the Paleontological Society jointly issue six times a year the *Journal of Paleontology*, J. Marvin Weller, Illinois Geological Survey, Urbana, Illinois, and C. Wythe Cooke, U. S. National Museum, Washington, D. C., editors: subscription, $6.00. The *Journal of Sedimentary Petrology*, W. H. Twenhofel, editor, University of Wisconsin, Madison, Wisconsin, is issued three times a year: subscription, $3.00. Single copies, *Journal of Paleontology*, $2.00; *Journal of Sedimentary Petrology*, $1.50. Society dues: with *Jour. Pal.*, $5.00; with *Jour. Sed. Petrology*, $3.00; with both, $8.00 per year.

AFFILIATED SOCIETIES

(Dates of affiliation in parentheses)

Alberta Society of Petroleum Geologists, Calgary, Alberta, Canada (31). Ian M. Cook, Secy., British American Oil Company
Appalachian Geological Society, Charleston, W. Virginia (31). Charles E. Stout, Secy., United Fuel Gas Co., Box 1273
Ardmore Geological Society, Ardmore, Oklahoma (36). S. L. Rose, Secy., 618 Simpson Building
Corpus Christi Geological Society, Corpus Christi, Texas (43). Elsie B. Chalupnik, Secy., Barnsdall Oil Co., 904 Driscoll Bldg.
Dallas Petroleum Geologists, Dallas, Texas (35). H. C. Vanderpool, Secy., Seaboard Oil Company, Continental Bldg.
East Texas Geological Society, Tyler, Texas (32). Russell Farmer, Secy., Stanolind Oil and Gas Company, Box 660
Fort Worth Geological Society, Fort Worth, Texas (31). Spencer R. Normand, Secy., Independent Exploration Company
Houston Geological Society, Houston, Texas (32). Charles H. Sample, Secy., J. M. Huber Corp., 721 Bankers Mortgage Bldg.
Illinois Geological Society (39). Everett F. Stratton, Secy., Schlumberger Well Surveying Corp., Box 491, Mattoon
Indiana-Kentucky Geological Society (38). Hillard W. Bodkin, Secy., Superior Oil Co., Evansville, Ind.
Kansas Geological Society, Wichita, Kansas (31). Delbert J. Costa, Secy., Superior Oil Co. of California, 417 First Natl. Bank
Michigan Geological Society (37). T. S. Knapp, Secy., Sohio Petroleum Company, 601 South Main, Mt. Pleasant
Mississippi Geological Society, Jackson, Miss. (41). F. F. Mellen, Secy., British-American Producing Co., 1007 Tower Bldg.
New Orleans Geological Society, New Orleans, La. (43). R. R. Copeland, Jr., Secy., The California Co., 1818 Canal Bldg.
North Texas Geological Society, Wichita Falls, Texas (38). David T. Richards, Secy., Shell Oil Co., Inc., Box 2010
Oklahoma City Geological Society, Oklahoma City, Okla. (31). C. E. Hamilton, Secy., Consolidated Gas Corp., Braniff Bldg.
Panhandle Geological Society, Amarillo, Texas (32). E. W. Sisney, Secy., Cities Service Gas Company, Box 350
Shawnee Geological Society, Shawnee, Oklahoma (31). Marcelle Mousley, Secy., Atlantic Refining Company, Box 169
Shreveport Geological Society, Shreveport, Louisiana (32). L. H. Meltzer, Secy., Union Producing Co., Box 1407, Zone 92
Society of Exploration Geophysicists, Houston, Tex. (32). W. Harlan Taylor, Secy., Petty Geophysical Engineering Co.
South Louisiana Geological Society, Lake Charles, La. (37). Ben F. Morgan, Secy., Stanolind Oil and Gas Company
Southeastern Geological Society, Tallahassee, Fla. (44). Edward W. Scott, Secy., Union Oil Co. of Calif., 622 N. Monroe St.
Tulsa Geological Society, Tulsa, Oklahoma (31). V. G. Hill, Secy., Stanolind Oil and Gas Company, Box 591
West Texas Geological Society, Midland, Texas (38). Jane Ferrell, Secy., Magnolia Petroleum Company, Box 633
Yellowstone-Bighorn Research Association, Inc. (44). W. T. Thom, Jr., Secy., Princeton, N. J.

HALOID RECORD

SEISMOGRAPH RECORDING PAPER IS FAVORED BY CRITICAL GEOPHYSICISTS

HALOID RECORD is plenty tough. It resists heat and withstands moisture. It provides sharp lines and legible contrast. Its processing advantages and consistently uniform performance even under the most adverse conditions of field and laboratory, make it the ideal paper for this work.

For superior seismographic recordings that successfully combine photographic excellence with an amazing ability to withstand abuse, use Haloid Record—the paper that's favored by critical geophysicists.

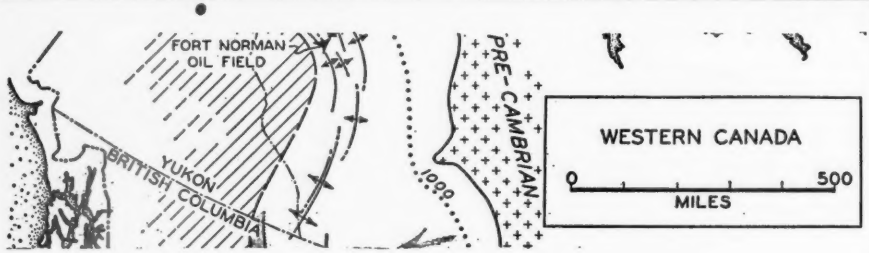
★ ★

BUY MORE WAR BONDS

★ ★

THE HALOID COMPANY

611 Haloid St., Rochester 3, N. Y.



1944 Printing in Paper Covers. Handy to Take with You

POSSIBLE FUTURE OIL PROVINCES OF THE UNITED STATES AND CANADA

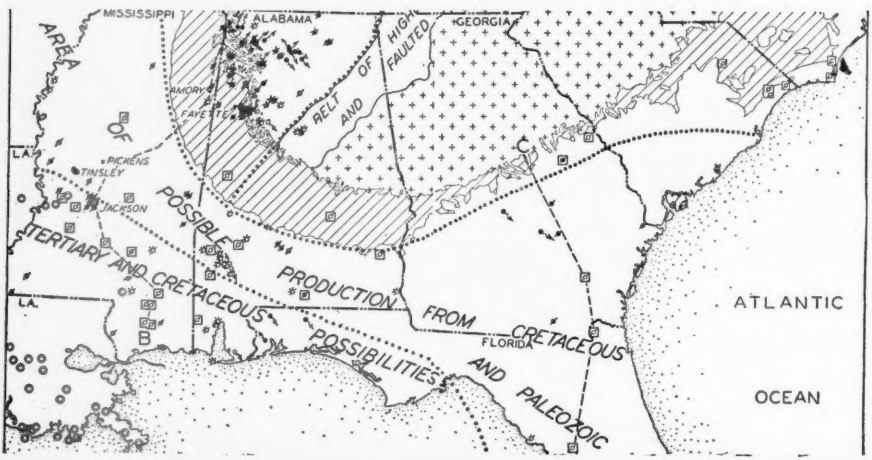
CONTENTS

Foreword	By A. I. Levorsen
Alaska	By Philip S. Smith
Western Canada	By Alberta Society of Petroleum Geologists
Pacific Coast States	By Pacific Section, American Association of Petroleum Geologists
Rocky Mountain Region	By Rocky Mountain Association of Petroleum Geologists
Northern Mid-Continent States	By Tulsa Geological Society
West Texas	By West Texas Geological Society
Eastern Canada	By Geological Survey of Canada, Quebec Bureau of Mines, and Newfoundland Geological Survey
Eastern United States	By Appalachian Geological Society
Southeastern United States	By Mississippi Geological Society

154 pp., 83 figs. Paper cover. 6 x 9 inches
Reproduced by photo offset process from original printing of 1941

PRICE, $1.50, POSTPAID ($1.00 TO MEMBERS AND ASSOCIATES)

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA 1, OKLAHOMA, U.S.A.



An A. A. P. G. Research Committee Symposium

PETROLEUM DISCOVERY METHODS

A CROSS SECTION OF EXPERT OPINION

Edited by A. I. LEVORSEN

1942

Nearly 200 men, whose business it is to know, replied to the questions:

> "Granted the premise of a satisfactory price; thinking of the problem from a broad point of view; and considering all of the modern techniques of geology, physics, chemistry, and engineering, which of the current methods or combination of methods, applied to oil exploration, do you regard as offering the most promise in maintaining an adequate oil and gas discovery rate in the foreseeable future? Which of the lesser ideas, techniques, or methods do you believe are of most significance and of increasing usefulness as guides to oil prospecting? In other words, what in your judgment is the best approach to the problem of oil and gas discovery?"

Whatever the answers, they should be of wide interest and value as being the considered opinions of a representative cross-section of independent thinking within our profession. The ideas expressed may well be a guide to much of the future exploration and point out to both geologists and executives many neglected fields of activity.—*From the Introduction.*

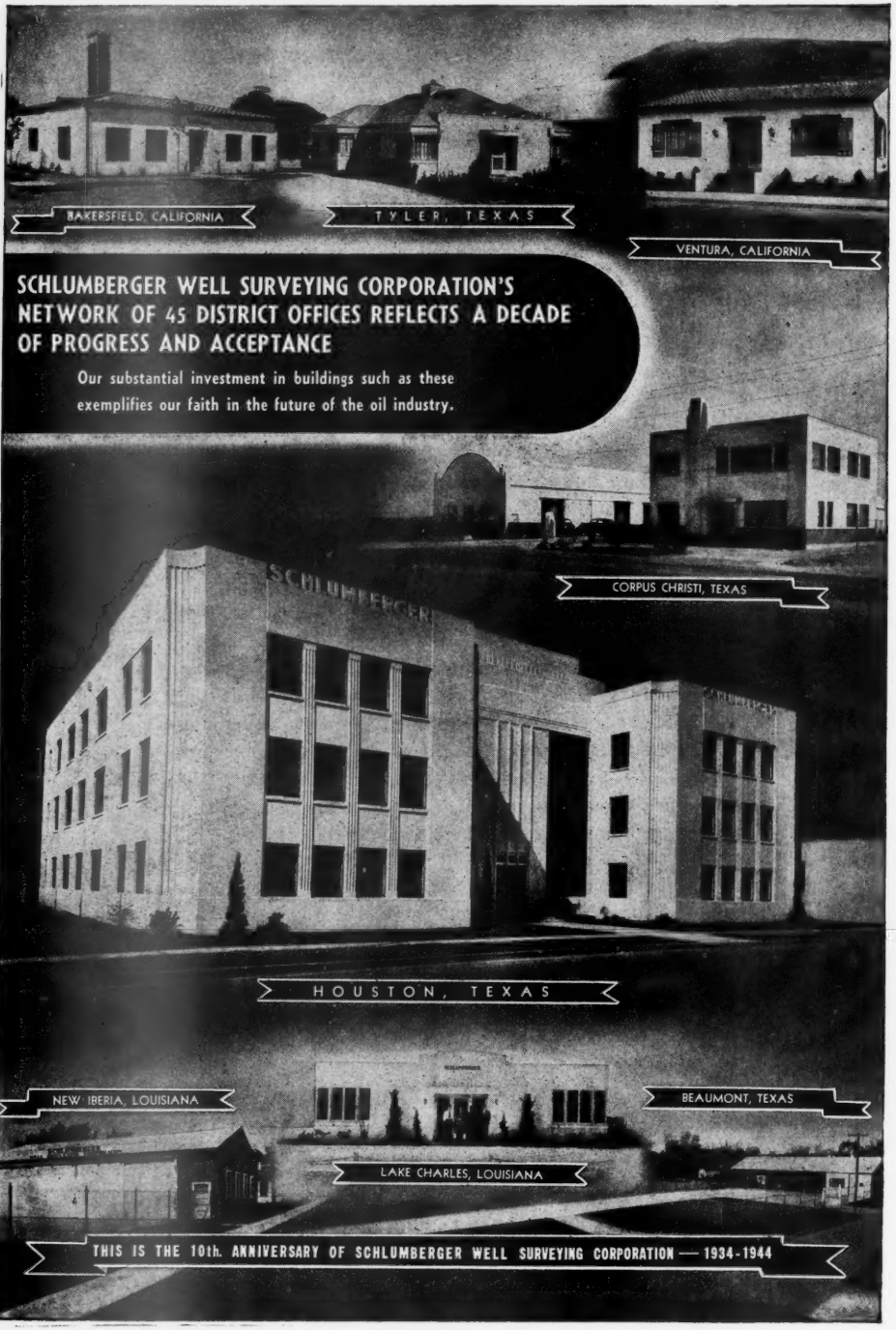
---

164 PP. LITHOPRINTED. 8.5 x 11 INCHES. PAPER COVER

PRICE, $1.00, POSTPAID

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

BOX 979, TULSA 1, OKLAHOMA, U.S.A.


BAKERSFIELD, CALIFORNIA
TYLER, TEXAS
VENTURA, CALIFORNIA
SCHLUMBERGER WELL SURVEYING CORPORATION'S NETWORK OF 45 DISTRICT OFFICES REFLECTS A DECADE OF PROGRESS AND ACCEPTANCE
Our substantial investment in buildings such as these exemplifies our faith in the future of the oil industry.
CORPUS CHRISTI, TEXAS
SCHLUMBERGER
HOUSTON, TEXAS
NEW IBERIA, LOUISIANA
BEAUMONT, TEXAS
LAKE CHARLES, LOUISIANA
THIS IS THE 10th. ANNIVERSARY OF SCHLUMBERGER WELL SURVEYING CORPORATION — 1934-1944

Bulletin Advertisers

Aero Service Corporation xxiv
American Paulin System .....
Atlas Powder Company .....
Baker Oil Tools, Inc. xxxiii
Baroid Sales Division xxix
Barret, William M., Inc. .....
Bausch and Lomb xxxiv
Core Laboratories .....
Dowell Incorporated viii
Drilling and Exploration Company, Inc. .....
Eastman Oil Well Surveys .....
Economic Geology Publishing Company .. xxiv
Engineering Laboratories, Inc. .....
Geo. E. Failing Supply Company .....
Federal Electric Company xxvi
First Natl. Bank and Trust Co. of Tulsa .. xviii
General Geophysical Company xxi
Geophysical Service, Inc. ..... Cover iii
Geotechnical Corporation xviii
Gravity Meter Exploration Company .....
Gulf Publishing Company xx
Haloid Company iii
Heiland Research Corporation .....
Hercules Powder Company, Inc. .....
Hughes Tool Company ..... Cover iv
Independent Exploration Company xxxv
Journal of Geology .....
Journal of Paleontology xviii
Journal of Sedimentary Petrology xviii
Keystone Exploration Company xxxii
Lane-Wells Company xxv
Laughlin-Simmons and Company .....
Lufkin Rule Company xviii
McCullough Tool Co. xvii
National Geophysical Company xxvii
Petty Geophysical Engineering Company ....
Reed Roller Bit Company x
Robert H. Ray, Inc. xxxvi
Rogers-Ray, Inc. xxxvii
Rouse Exploration Drilling Co. .....
Schlumberger Well Surveying Corporation .. vi
Seismic Explorations, Inc. xxiii
Seismograph Service Corporation .... Cover ii
Society of Exploration Geophysicists .....
Spencer Lens Company .....
Sperry-Sun Well Surveying Company .....
Sullivan Machinery Company .....
Thompson Tool Company, Inc. xxii
Tobin Aerial Surveys .....
Torsion Balance Exploration Company .....
Triangle Blue Print and Supply Company . xxiv
United Geophysical Company xxx
Wallace & Tiernan Products, Inc. xxi
Western Geophysical Company xix

PROFESSIONAL CARDS

California iv
Colorado ix
Illinois ..... ix-x
Indiana ix
Louisiana x
Mississippi x
New York x
Ohio x
Oklahoma ..... x, xi
Pennsylvania xi
Texas ..... xi, xii, xiii
West Virginia xiii
Wyoming xiii

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

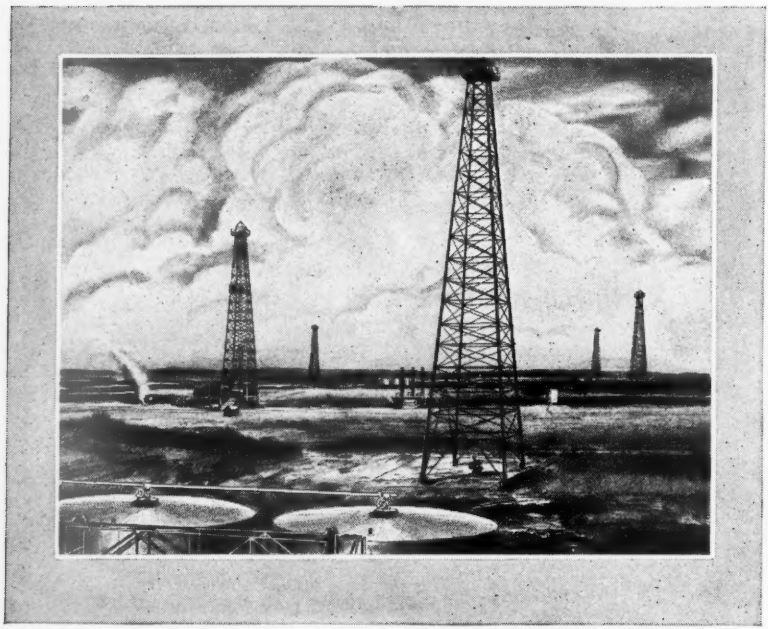
Appalachian xvi
Ardmore xv
Corpus Christi xv
Dallas xv
East Texas xvi
Exploration Geophysicists . xvi
Fort Worth xvi
Houston xvi
Illinois xiv
Indiana-Kentucky xiv
Kansas xiv
Michigan xiv
Mississippi xv
New Orleans xiv
North Texas xvi
Oklahoma City xv
Rocky Mountain xiv
Shawnee xv
Shreveport xiv
South Louisiana xiv
South Texas xvi
Tulsa xv
West Texas xvi

Articles for December *Bulletin*

Regional Subsurface Stratigraphy and Structure of Florida and Southern Georgia

By Paul L. Applin and Esther R. Applin

Annual Index, Volume 28 (1944)



YOUR UNDERGROUND AGENT—THE FACT-FINDING

Electric Pilot

Everything of importance to fully effective acidizing is revealed through the all-seeing fact-finding eye of the Dowell Electric Pilot.

As a result of its unerring findings, treating acid is directed to—and only to—the productive zones. Useless sections are located but ignored, and thus unnecessary expense is spared.

By accurately revealing the permeable zones, this Dowell service gets the facts which make maximum production possible—whether in completion, workover or secondary recovery.

The full story can be had from your local Dowell man . . . or write to us at Tulsa.

DOWELL INCORPORATED
Executive Office: Midland, Michigan
General Office: TULSA 3, OKLAHOMA
Subsidiary of The Dow Chemical Co.

Look to
DOWELL
FOR OIL AND GAS WELL CHEMICAL SERVICE

Volume 28 Number 11

BULLETIN
of the
AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

NOVEMBER, 1944

PROBLEMS OF UNDERGROUND GAS STORAGE IN OHIO, WEST VIRGINIA, AND PENNSYLVANIA[1]

F. H. FINN,[2] J. J. SCHMIDT,[3] AND J. B. CORRIN, JR.[4]
Pittsburgh, Pennsylvania

Underground storage of natural gas has been known to the industry for many years. However, the practice of storing gas was limited to a few isolated areas until the last 6 years. The period from 1937 to the present has witnessed a phenomenal increase in the number of storage areas utilized by natural gas companies. It can properly be called the time when storage became of age and asserted its rightful place. The gas industry had long been plagued by the bugaboo of "feast and famine," as represented in peak- and minimum-day demands from the marketing standpoint and by alternate periods of flush and lean supply from the standpoint of production.

The unprecedented requirements for natural gas occasioned by the war are partially responsible for the inauguration of many storage projects. Nevertheless, it is doubtful if storage on such a large scale would have been resorted to had it not been for the "know how" which was provided in the 10-year period prior to the war as a result of the technical evolution which has gradually taken place in our industry. The adoption of production engineering methods and geological thinking provided the tool whereby storage projects could be planned out and entered into safely without the fear of losing forever the large and valuable quantities of gas which must be returned to the earth as the first step in underground storage.

[1] A paper from the experience of the Consolidated Natural Gas Company, presented before the American Gas Association, Natural Gas Department, Natural Gas Spring Conference, French Lick, Indiana, May 11–13, 1944. Reprinted by permission from *Symposium on Natural Gas Storage*, American Gas Association, Natural Gas Department, 420 Lexington Avenue, New York 17, N. Y. (1944), pp. 8–30.

The writers wish to express their appreciation to the management of the Consolidated Natural Gas Company and to the respective managements of the subsidiary companies for permission to use company information in this report. They also wish to acknowledge and thank C. B. Board, Jr., and other members of the geological departments of The Peoples Natural Gas Company and The East Ohio Gas Company for much valuable assistance which was given by them in connection with the preparation of the paper.

[2] The Peoples Natural Gas Company.

[3] The East Ohio Gas Company.

[4] Hope Natural Gas Company.

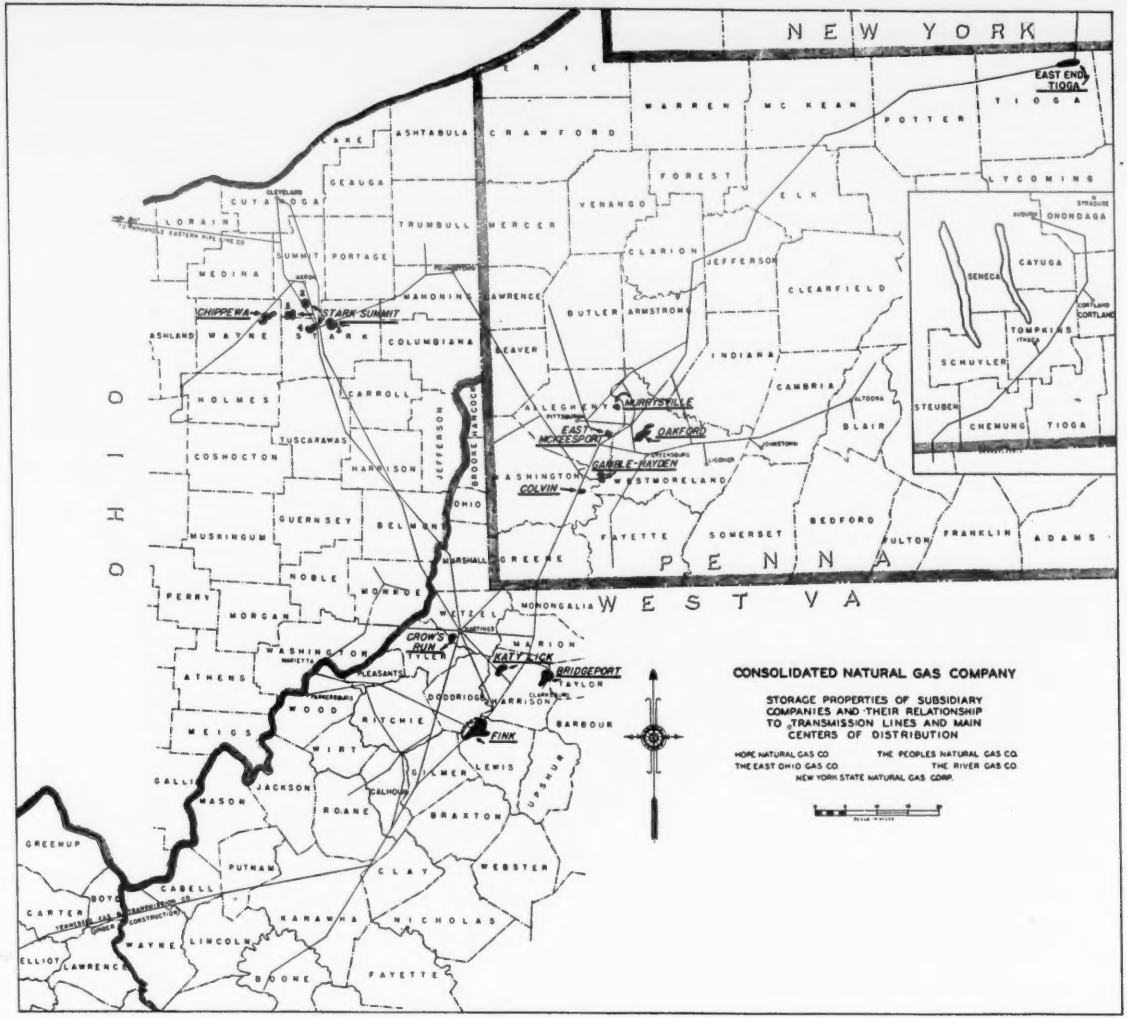


FIG. 1

TABLE NO. 1

TABULATION OF PERTINENT DATA ON STORAGE POOLS

FIG. 1

TABLE NO. 1

TABULATION OF PERTINENT DATA ON STORAGE POOLS

OPERATED BY HOPE NATURAL GAS COMPANY

					TOTALS
NAME OF POOL	FINK	BRIDGEPORT	KATY LICK	CROW'S RUN	
LOCATION:					
COUNTY	LEWIS	HARRISON-TAYLOR	HARRISON	WETZEL	
STATE	WEST VIRGINIA	WEST VIRGINIA	WEST VIRGINIA	WEST VIRGINIA	
GEOLOGICAL TYPE OF POOL	POROSITY LENS	POROSITY LENS	POROSITY LENS	POROSITY LENS	
STORAGE HORIZON	GANTZ SAND	50' SAND	MAXON SAND	BIG INJUN SAND	
ACRES IN POOL	8,100 (GAS) 2,800 (OIL)	2,818	700	1,215	18,633
WELLS IN POOL:					
INPUT	23	11	2	3	39
OUTPUT	54	26	3	4	87
DATE STORAGE STARTED	MAY 1, 1941	JULY 1, 1937	AUGUST 6, 1942	JUNE 6, 1941	
NATURAL RESERVE BEFORE STORAGE STARTED	1,916,000 M C.F.	830,000 M C.F.	201,000 M C.F.	745,000 M C.F.	3,692,000 M C.F.
METHOD OF INPUT (PUMPED OR NOT PUMPED)	PUMPED	PUMPED	NOT PUMPED	PUMPED	
METHOD OF OUTPUT (PUMPED OR NOT PUMPED)	PUMPED OR BY-PASSED	PUMPED OR BY-PASSED	NATURAL FLOW	NATURAL FLOW	
UPPER LIMIT OF PRESSURE FOR POOL TO DATE	204#	380#	87#	197#	
CAPACITY AT ABOVE PRESSURE	9,467,917 M C.F.	5,360,336 M C.F.	525,860 M C.F.	750,269 M C.F.	16,104,382 M C.F.
APPROXIMATE AMOUNT OF GAS PER LB. PRESSURE	47,897 M C.F.	11,912 M C.F.	7,730 M C.F.	5,036 M C.F.	72,575 M C.F.
AMOUNT OF GAS PER LB. STEADY WITHDRAWAL	34,900 M C.F.	10,225 M C.F.	6,000 M C.F.	4,573 M C.F.	55,698 M C.F.
AMOUNT OF GAS PER LB. INTERMITTENT WITHDRAWAL	-	-	-	-	
AMOUNT OF GAS IN STORAGE APRIL 1, 1943	6,332,411 M C.F.	3,803,513 M C.F.	188,883 M C.F.	532,350 M C.F.	10,857,157 M C.F.
AMOUNT OF GAS IN STORAGE DECEMBER 1, 1943	7,922,093 M C.F.	4,695,732 M C.F.	525,860 M C.F.	750,269 M C.F.	13,893,954 M C.F.
AMOUNT OF GAS IN STORAGE APRIL 1, 1944	4,907,000 M C.F.	2,430,000 M C.F.	284,000 M C.F.	510,000 M C.F.	8,131,000 M C.F.
NET GAS INJECTED DURING STORAGE CYCLE - APRIL 1 TO DECEMBER 1, 1943	1,589,682 M C.F.	892,219 M C.F.	336,977 M C.F.	217,919 M C.F.	3,036,797 M C.F.
NET GAS WITHDRAWN DURING WITHDRAWAL CYCLE - DECEMBER 1, 1943 TO APRIL 1, 1944	3,015,093 M C.F.	2,265,732 M C.F.	241,860 M C.F.	240,269 M C.F.	5,762,954 M C.F.
ROCK PRESSURE APRIL 1, 1943	123#	245# (247# N 225# S	40#	149#	
ROCK PRESSURE DECEMBER 1, 1943	155#	310# (322# N 289# S	86#	190#	
ROCK PRESSURE APRIL 1, 1944	124# ?	140# ?	50# ?	150# ?	
# (MAXIMUM WITHDRAWALS - STEADY WITHDRAWALS/24 HRS	56,715 M C.F.	44,878 M C.F.	3,972 M C.F.	3,000 M C.F.	108,565 M C.F.
# (MAXIMUM WITHDRAWALS - INTERMITTENT WITHDRAWALS/24 HRS	61,350 M C.F.	49,459 M C.F.	4,241 M C.F.	3,500 M C.F.	118,550 M C.F.
MAXIMUM INPUT IN 24 HRS. - ACTUAL	55,380 M C.F.	27,083 M C.F.	6,608 M C.F.	2,600 M C.F.	91,671 M C.F.
MINIMUM AMOUNT OF GAS REQUIRED AS CUSHIONS FOR DELIVERABILITY	3,000,000 M C.F.	1,500,000 M C.F.	250,000 M C.F.	400,000 M C.F.	5,150,000 M C.F.
WITHDRAWAL RATE AT CUSHION PRESSURE	8,000 M C.F.	8,000 M C.F.	1,000 M C.F.	1,000 M C.F.	18,000 M C.F.
PRESSURE WITH MINIMUM CUSHION	80#	100#	40#	125#	
PRESSURE OF POOL IF FILLED TO CAPACITY	500#	450#	300#	200#	
AMOUNT OF GAS STORED AT ABOVE CAPACITY	21,000,000 M (GAS) 3,000,000 M (OIL)	6,430,000 M C.F.	1,632,000 M C.F.	750,000 M C.F.	32,812,000 M C.F.

EXPERIENCE TO DATE

TABLE NO. 2

TABULATION OF PERTINENT DATA ON STORAGE POOLS

OPERATED BY THE EAST OHIO GAS COMPANY

NAME OF POOL	CHIPPEWA	STARK-SUMMIT POOL AREA 1	STARK-SUMMIT POOL AREA 2	STARK-SUMMIT POOL AREA 3	STARK-SUMMIT POOL AREA 4	TOTALS
LOCATION:						
COUNTY	WAYNE	SUMMIT	SUMMIT	STARK	STARK	
STATE	OHIO	OHIO	OHIO	OHIO	OHIO	
GEOLOGICAL TYPE OF POOL	POROSITY LENS	POROSITY LENS	POROSITY LENS	POROSITY LENS	POROSITY LENS	
STORAGE HORIZON	CLINTON SAND	CLINTON SAND	CLINTON SAND	CLINTON SAND	CLINTON SAND	
ACRES IN POOL	6,000	4,500	3,000	7,000	8,200	28,700
WELLS IN POOL:						
INPUT	14	21	11	18	10	74
OUTPUT	18	33	34	102	127	314
DATE STORAGE STARTED	OCTOBER 31, 1941	AUGUST 30, 1941	JULY 1, 1943	SEPTEMBER 17, 1943	SEPTEMBER 17, 1943	
NATURAL RESERVE BEFORE STORAGE STARTED	3,250,560 M C.F.	2,488,989 M C.F.	2,413,000 M C.F.	8,125,000 M C.F.	7,150,000 M C.F.	23,427,549 M C.F.
METHOD OF INPUT (PUMPED OR NOT PUMPED)	PUMPED	PUMPED	PUMPED	PUMPED	PUMPED	
METHOD OF OUTPUT (PUMPED OR NOT PUMPED)	NATURAL FLOW	PUMPED	PUMPED	NATURAL FLOW	NATURAL FLOW	
UPPER LIMIT OF PRESSURE FOR POOL TO DATE	950#	750#	375#	400#	400#	
CAPACITY AT ABOVE PRESSURE	1,844,038 M C.F.	1,735,742 M C.F.				3,579,880 M C.F.
APPROXIMATE AMOUNT OF GAS PER LB. PRESSURE	3,450 M C.F.	3,560 M C.F.				
AMOUNT OF GAS PER LB. STEADY WITHDRAWAL	NO DATA	-				
AMOUNT OF GAS PER LB. INTERMITTENT WITHDRAWAL	1,500 M C.F.	-				
AMOUNT OF GAS IN STORAGE APRIL 1, 1943	1,259,866 M C.F.	944,632 M C.F.				2,204,498 M C.F.
AMOUNT OF GAS IN STORAGE DECEMBER 1, 1943	1,757,801 M C.F.	1,729,349 M C.F.	NEW			3,487,150 M C.F.
AMOUNT OF GAS IN STORAGE APRIL 1, 1944	1,676,160 M C.F. (EST.)	1,386,499 M C.F. (EST.)				3,062,659 M C.F. (EST.)
NET GAS INJECTED DURING STORAGE CYCLE - APRIL 1 TO DECEMBER 1, 1943	497,935 M C.F.	784,717 M C.F.	AREAS			1,282,652 M C.F.
NET GAS WITHDRAWN DURING WITHDRAWAL CYCLE - DECEMBER 1, 1943 TO APRIL 1, 1944	81,641 M C.F.	342,850 M C.F.				424,491 M C.F.
ROCK PRESSURE APRIL 1, 1943	750#	450#				
ROCK PRESSURE DECEMBER 1, 1943	950#	600#	FIGURES			
ROCK PRESSURE APRIL 1, 1944	850#	530#				
(MAXIMUM WITHDRAWALS - STEADY WITHDRAWALS/24 HRS.	15,000 M C.F.	7,000 M C.F.				22,000 M C.F.
ø (MAXIMUM WITHDRAWALS - INTERMITTENT WITHDRAWALS/24 HRS.	22,000 M C.F.	9,500 M C.F.	OMITTED			31,500 M C.F.
MAXIMUM INPUT IN 24 HRS. - ACTUAL	6,500 M C.F.	7,000 M C.F.				13,500 M C.F.
MINIMUM AMOUNT OF GAS REQUIRED AS CUSHION FOR DELIVERABILITY	500,000 M C.F.	1,000,000 M C.F.				1,500,000 M C.F.
WITHDRAWAL RATE AT CUSHION PRESSURE	5,000 M C.F.	4,000 M C.F.				9,000 M C.F.
PRESSURE WITH MINIMUM CUSHION	400#	450#				
PRESSURE IN POOL IF FILLED TO CAPACITY	975#	850#				
AMOUNT OF GAS STORED AT ABOVE CAPACITY	2,250,000 M C.F.	3,000,000 M C.F.				5,250,000 M C.F.

ø EXPERIENCE TO DATE

TABLE NO. 3

TABULATION OF PERTINENT DATA ON STORAGE POOLS

EXPERIENCE TO DATE

TABLE No. 3

TABULATION OF PERTINENT DATA ON STORAGE POOLS

OPERATED BY THE PEOPLES NATURAL GAS COMPANY

NAME OF POOL	MURRYSVILLE	EAST MCKEESPORT	GAMBLE-HAYDEN	COLVIN	OAKFORD*	TOTALS
LOCATION:						
COUNTY	ALLEGHENY	ALLEGHENY	ALLEGHENY	WASHINGTON	WESTMORELAND	
STATE	PENNSYLVANIA	PENNSYLVANIA	PENNSYLVANIA	PENNSYLVANIA	PENNSYLVANIA	
GEOLOGICAL TYPE OF POOL	POROSITY LENS PEAK LOAD	POROSITY LENS PEAK LOAD AND CONT. SUPPLY	MULTIPLE POROSITY LENS PEAK LOAD AND CONT. SUPPLY	POROSITY LENS PEAK LOAD	MULTIPLE POROSITY LENS CONT. SUPPLY AND EXCESS GAS	
STORAGE HORIZON	100' SAND	100' SAND	BAYARD AND BIG INJUN SANDS	MURRYSVILLE SAND	MURRYSVILLE, 5TH AND BAYARD	
ACRES IN POOL	537 (+366 - H20)	436	644	500	6332	8449
WELLS IN POOL:						
INPUT	3	3	6	3	21	36
OUTPUT	3	3 TO 6	11	3	21	41 TO 44
DATE STORAGE STARTED	AUGUST 8, 1939	OCTOBER 7, 1941	JUNE 9, 1943	JUNE 21, 1943	MAY, 1937	
NATURAL RESERVE BEFORE STORAGE STARTED	61,000 M C.F.	61,080 M C.F.	600,000 M C.F.	35,000 M C.F.	1,280,000 M C.F.	2,037,000 M
METHOD OF INPUT (PUMPED OR NOT PUMPED)	PUMPED	PUMPED	PUMPED	NATURAL FLOW AND PUMPED	NATURAL FLOW	
METHOD OF OUTPUT (PUMPED OR NOT PUMPED)	NATURAL FLOW AND PUMPED	NATURAL FLOW AND PUMPED	NATURAL FLOW AND PUMPED	NATURAL FLOW AND PUMPED	PUMPED	
UPPER LIMIT OF PRESSURE FOR POOL TO DATE	478#	359#	359#	165#	22#	
CAPACITY AT ABOVE PRESSURE	1,010,220 M C.F.	1,459,838 M C.F.	290,877 M C.F.	246,816 M C.F.	2,433,388 M C.F.	5,441,139 M
APPROXIMATE AMOUNT OF GAS PER LB. PRESSURE	2,200 M/LB.	3,800 M/LB.	2,000 M/LB.	2,000 M/LB.	160,000 M TO 200,000 M	
AMOUNT OF GAS PER LB. STEADY WITHDRAWAL	1,000 M/LB.	2,000 M/LB.	2,000 M/LB.	1,200 M/LB.	160,000 M TO 200,000 M	
AMOUNT OF GAS PER LB. INTERMITTENT WITHDRAWAL	1,500 M/LB. TO 2,000 M/LB.	3,500 M/LB.	2,000 M/LB.	1,500 M/LB.	160,000 M TO 200,000 M	
AMOUNT OF GAS IN STORAGE APRIL 1, 1943	869,610 M C.F.	971,106 M C.F.	0	0	415,406 M C.F.	2,256,122 M
AMOUNT OF GAS IN STORAGE DECEMBER 1, 1943	1,008,024 M C.F.	1,415,963 M C.F.	290,877 M C.F.	246,816 M C.F.	116,958 M C.F.	3,078,638 M
AMOUNT OF GAS IN STORAGE APRIL 1, 1944	600,286 M C.F.	800,957 M C.F.	54,647 M C.F.	140,339 M C.F.	0	1,596,229 M
NET GAS INJECTED DURING STORAGE CYCLE - APRIL 1 TO DECEMBER 1, 1943	138,414 M C.F.	444,857 M C.F.	290,877 M C.F.	246,816 M C.F.	(WITHDRAWAL) (298,448)	822,516 M
NET GAS WITHDRAWN DURING WITHDRAWAL CYCLE - DECEMBER 1, 1943 TO APRIL 1, 1944	407,738 M C.F.	615,006 M C.F.	236,230 M C.F.	106,477 M C.F.	116,958 M C.F.	1,482,409 M
ROCK PRESSURE APRIL 1, 1943	428#	303#	228# (JUNE 9, 1943)	14# (JUNE 21, 1943)	13.1#	
ROCK PRESSURE DECEMBER 1, 1943	457#	337#	359#	165#	14.0#	
ROCK PRESSURE APRIL 1, 1944	100#	135#	236#	86#	13.5#	
(MAXIMUM WITHDRAWALS - STEADY WITHDRAWALS/24 HRS.	10,000 M C.F.	11,000 M C.F.	5,000 M C.F.	2,500 M C.F.	3,650 M C.F.	32,150 M
(MAXIMUM WITHDRAWALS - INTERMITTENT WITHDRAWALS/24 HRS.	15,000 M C.F.	22,000 M C.F.	10,000 M C.F.	5,000 M C.F.	3,650 M C.F.	55,650 M
MAXIMUM INPUT IN 24 HRS. - ACTUAL	2,756 M C.F.	5,183 M C.F.	3,094 M C.F.	3,105 M C.F.	8,889 M C.F.	23,027 M
MINIMUM AMOUNT OF GAS REQUIRED AS CUSHION FOR DELIVERABILITY	158,000 M C.F.	129,000 M C.F.	NO STORAGE GAS REQUIRED	90,000 M C.F.	NO STORAGE GAS REQUIRED	377,000 M
WITHDRAWAL RATE AT CUSHION PRESSURE	2,000 M TO 5,000 M	3,000 M	2,500 M TO 4,000 M	2,000 M C.F.	3,000 M C.F.	12,500 M TO 17,000 M
PRESSURE WITH MINIMUM CUSHION	100#	50#	200#	50#	8#	
PRESSURE OF POOL IF FILLED TO CAPACITY	500#	500#	500#	500#	*	
AMOUNT OF GAS STORED AT ABOVE CAPACITY	1,050,000 M C.F.	1,950,000 M C.F.	1,300,000 M C.F.	1,000,000 M C.F.	*	5,300,000 M

EXPERIENCE TO DATE

*THIS POOL NO LONGER USED FOR STORAGE PURPOSES

TABLE NO. 4

TABULATION OF PERTINENT DATA ON STORAGE POOLS

OPERATED BY NEW YORK STATE NATURAL GAS CORPORATION

NAME OF POOL	EAST END TIOGA
LOCATION:	
COUNTY	TIOGA
STATE	PENNSYLVANIA
GEOLOGICAL TYPE OF POOL	CLOSED STRUCTURE
STORAGE HORIZON	ORISKANY
ACRES IN POOL	2,766
WELLS IN POOL:	
INPUT	5
OUTPUT	5
DATE STORAGE STARTED	JULY 6, 1940
NATURAL RESERVE BEFORE STORAGE STARTED	592,000 M C.F.
METHOD OF INPUT (PUMPED OR NOT PUMPED)	PUMPED
METHOD OF OUTPUT (PUMPED OR NOT PUMPED)	NATURAL FLOW AND PUMPED
UPPER LIMIT OF PRESSURE FOR POOL TO DATE	338#
CAPACITY AT ABOVE PRESSURE	2,755,215 M C.F.
APPROXIMATE AMOUNT OF GAS PER LB. PRESSURE	9,000 M C.F.
AMOUNT OF GAS PER LB. STEADY WITHDRAWAL	6,000 M C.F.
AMOUNT OF GAS PER LB. INTERMITTENT WITHDRAWAL	9,000 M C.F.
AMOUNT OF GAS IN STORAGE APRIL 1, 1943	1,814,393 M C.F.
AMOUNT OF GAS IN STORAGE DECEMBER 1, 1943	2,643,621 M C.F.
AMOUNT OF GAS IN STORAGE APRIL 1, 1944	1,282,686 M C.F.
NET GAS INJECTED DURING STORAGE CYCLE - APRIL 1 TO DECEMBER 1, 1943	829,228 M C.F.
NET GAS WITHDRAWN DURING WITHDRAWAL CYCLE - DECEMBER 1, 1943 TO APRIL 1, 1944	1,360,935 M C.F.
ROCK PRESSURE APRIL 1, 1943	240#
ROCK PRESSURE DECEMBER 1, 1943	315#
ROCK PRESSURE APRIL 1, 1944	120#
(MAXIMUM WITHDRAWALS - STEADY WITHDRAWALS/24 HRS	19,769 M C.F.
(MAXIMUM WITHDRAWALS - INTERMITTENT WITHDRAWALS/24 HRS	30,000 M C.F.
MAXIMUM INPUT IN 24 HRS. - ACTUAL	10,492 M C.F.
MINIMUM AMOUNT OF GAS REQUIRED AS CUSHION FOR DELIVERABILITY	397,000 M C.F.
WITHDRAWAL RATE AT CUSHION PRESSURE	8,000 M C.F.
PRESSURE WITH MINIMUM CUSHION	100#
PRESSURE OF POOL IF FILLED TO CAPACITY	500#
AMOUNT OF GAS STORED AT ABOVE CAPACITY	4,500,000 M C.F.

ø EXPERIENCE TO DATE

TABLE NO. 5

TABULATION OF PERTINENT DATA ON ACTIVE
STORAGE POOLS OPERATED BY
SUBSIDIARIES OF CONSOLIDATED NATURAL GAS COMPANY*

ACRES IN ACTIVE STORAGE POOLS	34,016
WELLS IN POOLS:	
INPUT	94
OUTPUT	166 (ALSO TOTAL WELLS)
DATE STORAGE STARTED	1937
NATURAL RESERVE OF ALL POOLS BEFORE STORAGE STARTED	10,780,549 M C.F.
LARGEST NON-COINCIDENTAL AMOUNT STORED (TO DATE)	25,447,228 M C.F.
CAPACITY OF POOLS (UPPER LIMITS)	47,862,000 M C.F.
TOTAL AMOUNT OF GAS IN STORAGE APRIL 1, 1943	16,716,764 M C.F.
TOTAL AMOUNT OF GAS IN STORAGE DECEMBER 1, 1943	22,986,405 M C.F.
TOTAL AMOUNT OF GAS IN STORAGE APRIL 1, 1944	14,072,574 M C.F.
NET GAS INJECTED DURING STORAGE CYCLE - APRIL 1, 1943 TO DECEMBER 1, 1943	6,269,641 M C.F.
NET GAS WITHDRAWN DURING WITHDRAWAL CYCLE - DECEMBER 1, 1943 TO APRIL 1, 1944	8,913,831 M C.F.
ø (MAXIMUM NON-COINCIDENTAL WITHDRAWALS - STEADY WITHDRAWALS/24 HRS	178,834 M C.F.
ø (MAXIMUM NON-COINCIDENTAL WITHDRAWALS - INTERMITTENT WITHDRAWALS/24 HRS	232,050 M C.F.
MAXIMUM NON-COINCIDENTAL INPUT IN 24 HRS. - ACTUAL	129,801 M C.F.
MINIMUM AMOUNT OF STORAGE GAS REQUIRED FOR CUSHION FOR DELIVERABILITY	7,424,000 M C.F.
WITHDRAWAL RATE AT ABOVE CUSHION	44,500 M C.F. TO 49,000 M C.F.

*DOES NOT INCLUDE DATA ON OAKFORD POOL (PEOPLES NATURAL GAS COMPANY), SINCE THIS POOL IS NO LONGER USED FOR STORAGE. DOES NOT INCLUDE DATA ON STARK-SUMMIT COUNTY AREAS #2, 3, AND 4, SINCE THESE POOLS ARE IN TESTING PHASE ONLY TO DATE.

ø EXPERIENCE TO DATE

At a symposium on storage held several years ago under the auspices of the American Gas Association, the experiences of The Peoples Natural Gas Company were reviewed.[5] The early operations described at that time represented the beginnings of storage endeavors by the companies which now comprise the Consolidated Natural Gas Company. Since that time, the various subsidiaries of the Consolidated have embarked upon storage projects throughout the Appalachian area which dwarf the early efforts.

The subsidiaries of the Consolidated Natural Gas Company are now operating underground storage projects in the states of Ohio, West Virginia, and Pennsylvania. The approximate location of the pools, with the relative positions of the transmission lines and the main centers of distribution, are shown in Figure 1. Both large and small capacity pools are being operated. In the year 1943, approximately 12 billion cubic feet of gas was stored, and an almost equal amount was withdrawn from the various projects. This undertaking has affected the company's operations in many ways and has given rise to some problems.

DESCRIPTION OF CONSOLIDATED NATURAL GAS COMPANY'S STORAGE PROJECTS

The various subsidiaries of Consolidated have operated or are testing fifteen underground storage areas and one liquid storage project. A tabulation of most of the pertinent data relating to these storage pools is given in Tables 1, 2, 3, 4, and 5. It includes information on the size and location of the pools, number of wells involved, capacity of the reservoir, geological type, deliverability, and other significant data. The reader is referred to these tables for detailed data on each pool.

HOPE NATURAL GAS COMPANY—STORAGE OPERATIONS

The Hope Natural Gas Company is principally concerned with the gathering of gas both from its own production and through purchase within and without the state of West Virginia. Sufficient gas production has been developed by Hope and its vendors to partially meet the winter requirements and to furnish an excess supply during the off-peak seasons. Therefore, it was important that Hope have storage pools of moderately large capacity, that is, pools which would hold considerable gas and which could be relied upon for relatively large deliverabilities over a long period during the winter months on a steady withdrawal basis.

Two of the four pools which Hope operates, and which are by far the most important of its storage projects, are moderately large pools. The Fink storage pool is located in Lewis County, West Virginia. This pool was originally a gas and oil pool, and the original accumulation of gas was due to an interruption in porosity in an updip direction. For the purpose of this report, this geological type of pool has been called a "porosity lens" type. The pool is located entirely on the west flank of an anticline, and there are approximately 8,100 acres of it which were formerly productive of gas. Farther downdip and contiguous to the gas

[5] F. H. Finn, "Our Experience with the Underground Storage of Gas (The Peoples Natural Gas Company)," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 8 (August, 1940), pp. 1482–94.

acreage are 5,800 acres from which oil has been produced. The producing sand which is used for storage is known as the Gantz sand, geologically a member of the Upper Devonian series of sediments. There are fifty-four gas wells in this pool.

To date, approximately 9½ billion feet of gas is the maximum amount which has been stored in the area at one time. When this amount of gas was stored, the rock pressure of the pool was 204 pounds per square inch. The pre-storage pressure of the pool had been about 40 pounds. When sufficient gas becomes available, the pool may be filled up to 500 pounds pressure, and under that pressure it is estimated it will hold 21 billion feet of gas in the gas portion of the pool and 3 billion feet of gas in the oil portion of the pool. Gas has been injected into this pool at the rate of 55 million cubic feet per day. The highest intermittent withdrawal rate from the field has been approximately 61 million feet per day. When the rock pressure of the pool was approximately 200 pounds, near its capacity to date, as much as 57 million per day was withdrawn on a steady basis. Approximately 48 million cubic feet of gas is required per pound rise of rock pressure on input for this project.

The Fink pool is of unusual interest because of the adjacent oil acreage. The oil geologist would have termed this oil and gas pool as a "gas cap" type of reservoir, in which the updip portion of the pool was filled with gas. There are one hundred and twenty-three oil wells in the oil field just west of the main pool. (See Figure 2 for relation of oil and gas wells.) At the start of the storage project, all of these oil wells were owned by the South Penn Natural Gas Company; therefore, it was necessary for Hope to make satisfactory arrangements with this company in order that it might recover any gas injected into storage which might migrate into the oil wells. It was found during preliminary tests for storage in the gas area that there was some migration of gas to several of the Gantz sand oil wells near the Hope input wells. An agreement was reached with the South Penn whereby all gas taken from the oil wells over a certain established daily amount would be returned to the Hope Natural Gas Company free of charge, while South Penn would retain all increased oil production due to the storage operation, which, of course, repressured the adjacent oil area. On March 1, 1943, Hope acquired the one hundred and twenty-three oil wells from South Penn in order to operate the Fink storage area more efficiently as a storage project.

It is worthy of note that prior to the storage of natural gas in this area, the pool was producing only 675 barrels of oil per week. The oil production had increased about two-thirds when storage was at its peak during the week of October 15, 1943. The increase in production came from forty-three of the oil wells, which are all that have been affected to date. The total increase in oil production due to gas storage from the time storage started, May 1, 1941, until April 1, 1944, amounts to 40,122 barrels. A total of 1,323,000 M c.f.[6] of storage gas was produced from the oil wells during the same period.

[6] M c.f.: 1,000 cubic feet.

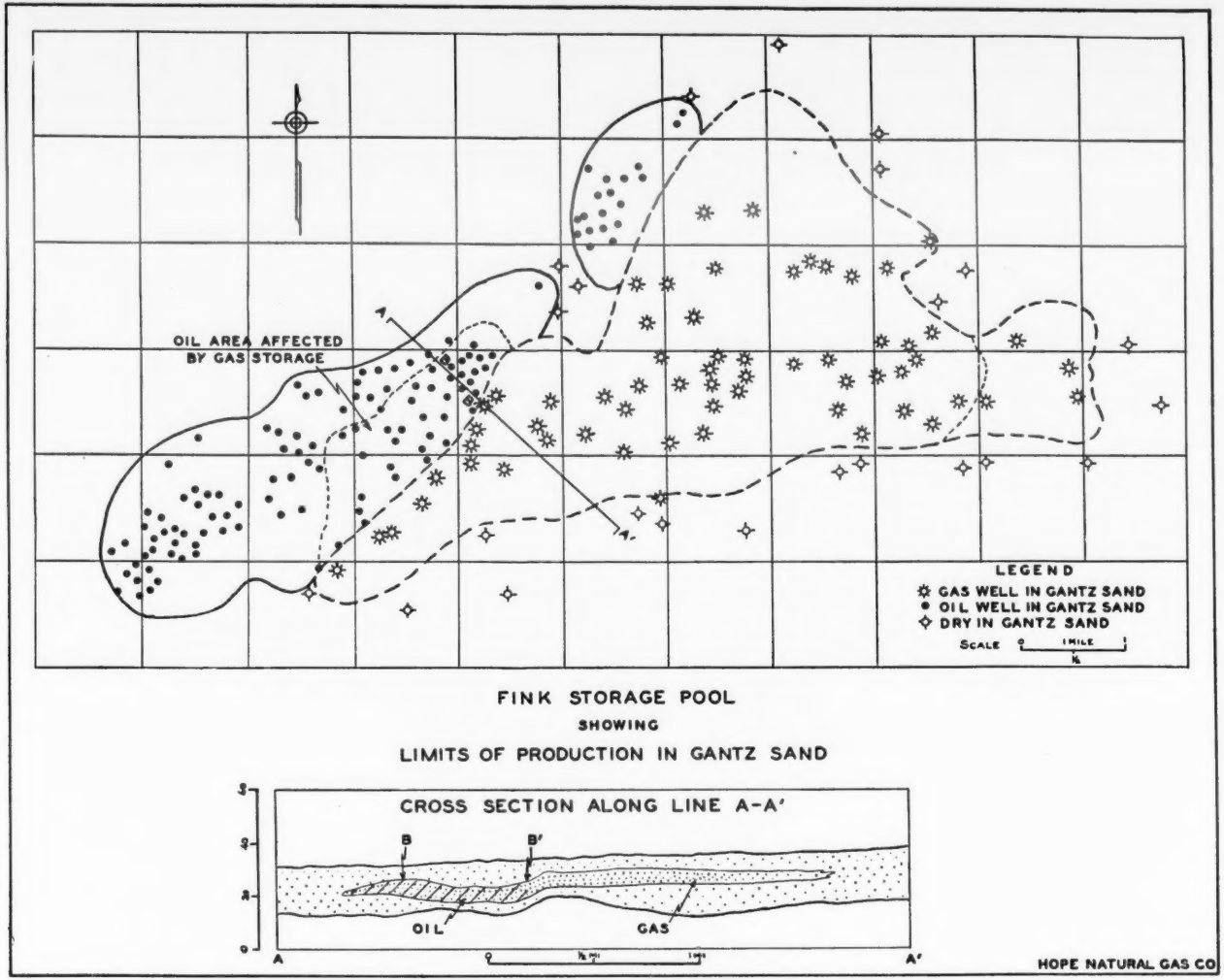

OIL AREA AFFECTED
BY GAS STORAGE
A
A'
B
B'
LEGEND
GAS WELL IN GANTZ SAND
OIL WELL IN GANTZ SAND
DRY IN GANTZ SAND
SCALE 0 1 MILE
FINK STORAGE POOL
SHOWING
LIMITS OF PRODUCTION IN GANTZ SAND
CROSS SECTION ALONG LINE A-A'
B
B'
OIL
GAS
A
A'
HOPE NATURAL GAS CO

FIG. 2

Early experience with this pool indicated that the output rate could be increased by pulling all 2-inch and 3-inch tubing from the gas wells in the storage area and recasing the wells with either 5-inch or 6-inch casing.

The output rate was further augmented by drilling seven new wells in the area. Two abandoned wells were redrilled and made good producers. The total open flow from the seven new wells drilled in the pool was 20,955 M c.f., and the two abandoned gas wells, which had been completely exhausted before storage started, yielded 3,034 M c.f. open flow.

This storage pool has been found to be very important in Hope's operations, and an impressive portion of the company's winter load has been supplied from the pool during the past two winters. However, it does necessitate storing a considerable amount of gas in order to obtain an economical deliverability rate, as the deliberability from this pool is only 8 million feet per day, with an approximate storage of 3 billion feet. The ratio of deliverability to gas stored increases rapidly after this "cushion" gas has been stored.

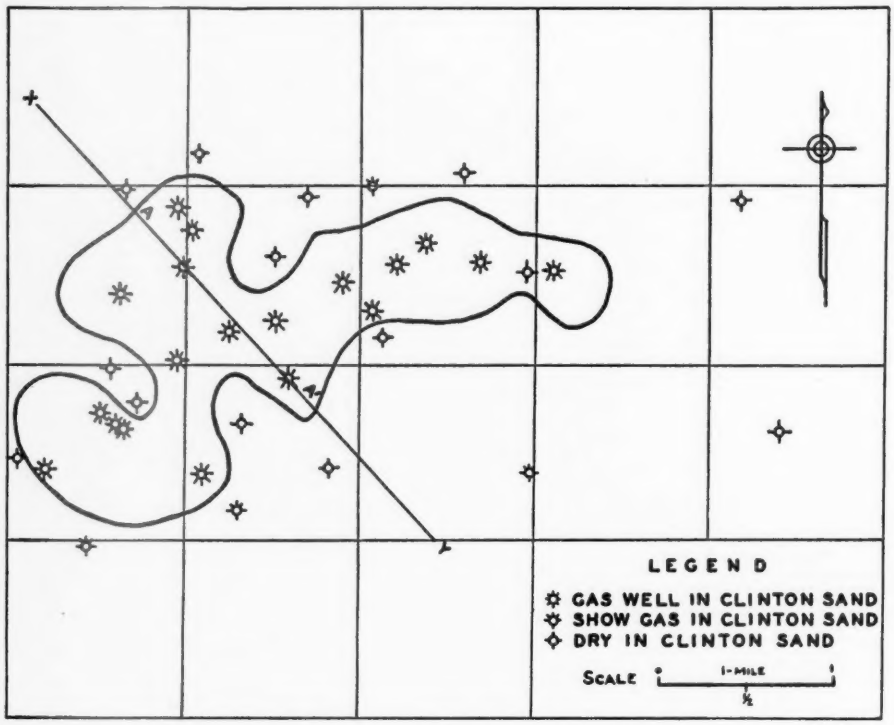
Hope's earliest storage project is known as the Bridgeport pool. In one portion of the pool, some very large wells were drilled when it was first discovered, some making as much as 25 million cubic feet open flow. The presence of these large wells led to a study of the area for storage possibilities. This pool was first tested for storage in May, 1932, and was selected after the test proved the extent of the drainage area. It is similar to the Fink pool in geological type, that is, a porosity lens type of accumulation in the 50-foot sand.

FIG. 2

The area was established as a storage pool, July 1, 1937, and it was found that the productive portion of the area was actually divided into two distinct pools, which are known as the Southern and Northern pools of the Bridgeport storage area. The Southern pool is smaller in area than the Northern pool but absorbs gas at a greater rate than the northern portion, because of the higher porosity and permeability of the sand. For the same reasons, the rate of output is greater from the Southern pool until the rock pressure drops considerably below that of the Northern pool.

During the past two input periods, all gas stored in the area has been dehydrated, as considerable trouble has been experienced with hydrate formation prior to that time. In fact, some difficulties of this type were encountered even after the first period of storage of dehydrated gas. Part of the difficulty was due to the constricted size of the pipe-line system, and after the lines had been enlarged and the wells recased, together with an increase in capacity of the compressing stations, the hydrate problem disappeared.

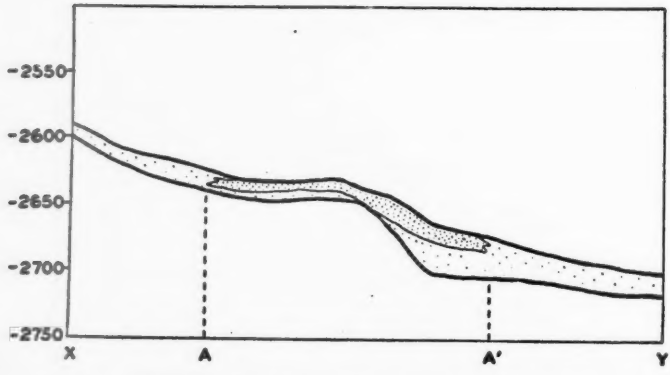
This pool is much smaller than the Fink pool, covering only 2,818 acres. The capacity of the pool at 450 pounds is estimated to be 6,430,000 M c.f. of gas, and it requires about 12 million feet of gas input to increase the rock pressure one pound. At one time, 5,360,000 M c.f. of gas had been stored in the pool, and the rock pressure had then risen to 380 pounds. At these high pressures, the pool delivered approximately 50 million per day under intermittent withdrawal con-



CHIPPEWA STORAGE POOL

SHOWING

LIMITS OF PRODUCTION
IN THE CLINTON SAND



CROSS SECTION ALONG LINE X-Y

THE EAST OHIO GAS CO

FIG. 3

ditions, and yielded gas at the rate of 45 million per day on a steady withdrawal basis.

This pool is considered ideal in size for the requirements of the Hope Natural Gas Company, and it will be used more extensively than the larger Fink area in the future, particularly during periods when there is not a very large supply of gas available for storage.

In addition to the two pools which have just been described, Hope operates two other pools of much smaller size, one known as the Katy Lick storage pool, located in Harrison County, West Virginia, and the other known as the Crow's Run project of Wetzel County, West Virginia. These pools are small and have not added much to the capacity of the Hope Company for long periods of withdrawal. (For detail on these pools, the reader is referred to Table 1.)

EAST OHIO GAS COMPANY—STORAGE OPERATIONS

From the date of incorporation of The East Ohio Gas Company in 1898 until 1909, the company purchased all of its gas from the Hope Natural Gas Company in West Virginia. Although this continued to be the major source of supply, after this date East Ohio purchased and produced some of its supply in Ohio.

Realizing that the hourly peaks of the developed markets could not be met by the available supply from West Virginia and Ohio, The East Ohio Gas Company completed a liquefaction storage plant in Cleveland in January, 1941.

This type of storage is particularly valuable for meeting sudden peaks in demand and has been very well described in a recent article by J. French Robinson, president of The East Ohio Gas Company, which appeared in the February issue of the *West Virginia Engineer*, published by West Virginia University. Charles F. Turner of The East Ohio Gas Company is giving a paper at this meeting on this subject.[7]

By 1941, it became apparent that East Ohio could not meet the prolonged daily peaks and periods of high seasonal demand from the ordinary supplies of produced and purchased gas, and since liquefied storage was limited to relatively small volumes of gas, it was decided to add underground storage facilities. After some study, five potential areas were selected. Storage operations were undertaken in two of these areas, the Chippewa pool and the Stark-Summit County Area No. I, in the latter part of 1941.

The general statistics on all of East Ohio are given in Table 2, and a map showing the sand structure in the Chippewa pool is shown in Figure 3.

The Chippewa pool, selected for use as a small, peak-load pool, is located in Chippewa Township, Wayne County, Ohio, in proximity to Barberton and Akron, Ohio, and is situated to allow for quick transportation of gas from the center of the pipe-line system to Cleveland.

Prior to storage, the eighteen wells in this pool delivered 2,300 M c.f. daily in the winter of 1940–1941, with a rock pressure of 330 pounds. This pool was

[7] American Gas Association, Natural Gas Department, Natural Gas Spring Conference, French Lick, Indiana, May 11–13, 1944.

drilled in 1918 and always had been used to meet peak loads because of its location and original high delivery. The field was shut in 8 months while the 1,020 horsepower compressor station was being erected and the pipe lines were being laid for storage. The station is located near the center of the field, and the flow system consists of solid welded pipe lines. This flow system serves the dual purpose of injecting or withdrawing gas, thereby requiring only one set of gates to be handled to store or withdraw gas. Gas can be shifted from withdrawal to storing within 15 minutes, and this is often done at times of highly changing load. By the time storage was actually started, the rock pressure had built up to 416 pounds.

The Chippewa pool produced 12,300 M c.f. per pound of pressure in its original state. However, because of the low average permeability of the pool, it has required much less gas per pound to build up the pressure during storage operations. This rapid pressure build-up has resulted in unusually high deliverability for the amount of gas stored. In the year 1943, slightly less than 2 billion feet of gas was in storage, and the well-head pressure had been increased to 950 pounds. With this amount of gas in storage, it was possible to deliver as much as 22 million feet per day from the project. Of course, it is necessary to put gas back into storage at frequent intervals in order to maintain a high deliverability rate for the pool and to make it advantageous for peak days. Since storage started in this pool, a total of 2,799,894 M c.f. has been pumped into the pool, and a total of 1,136,662 M c.f. has been withdrawn.

East Ohio's Area I, in the Stark-Summit pool, is located in Franklin Township, Summit County. This area is larger than the Chippewa pool, having thirty-three wells. Since it had a greater reservoir and a lower pressure to start with, it has not reached the high daily deliverability of the Chippewa area, although it had a net of 1,652,370 M c.f. in storage as of December 31, 1943, which had been put in since pumping started, August 31, 1941. The total gas withdrawn during 1943 was 427,666 M c.f. from this area. The daily rate of withdrawal holds up well, ranging between $8\frac{1}{2}$ million and 7 million per day during the past few months. As soon as gas is available, this area can be developed into a high daily deliverability project with an additional 1 billion cubic feet of storage gas.

In 1942, East Ohio decided to extend storage into Areas II, III, and IV in the Stark-Summit pool. This pool in its entirety contains 576 active wells and covers an area of 45,000 acres.

Two facts were obvious at the outset. It would be necessary to select only the smaller and most concentrated areas of large open-flow wells for storage, and it would be necessary to gain control of the wells owned by other companies and independent operators in this field, so that there would be no outside interference with the storage project. In the Chippewa pool and Area I, there had been only a relatively small amount of this work, although one well was owned by one hundred and twenty-five individuals.

The Ohio Fuel Gas Company owned seventy-four wells and 4,500 acres in the

Stark-Summit County field. An agreement was made with Ohio Fuel whereby lines and wells in this area were exchanged for similar properties of East Ohio in other areas. Other interests, ranging from small fractional parts in a well to sixty-five wells, have been purchased and traded. The leases have been changed by agreements to permit storage, and royalties have been changed to flat annual rentals. A new compressor station of 3,000 horsepower was built.

All East Ohio stations will pump into storage at 1,100 pounds. The stations can pump daily approximately 45,000 M c.f.

Actual storage in Stark-Summit Areas II, III, and IV was started last year by East Ohio. These areas contain thirty-four, one hundred and two, and one hundred and twenty-seven wells, respectively. While the data on these areas is not complete, Area II is similar to Chippewa and should somewhat follow its performance, and Areas III and IV will each be approximately twice the size of Area I. These areas are excellently located for East Ohio, and when sufficient gas is available for storage, they should be very effective, Area II as peak-day project, and Areas III and IV, the larger areas, being more suitable for low-pressure, long-period, steady-withdrawal pools.

THE PEOPLES NATURAL GAS COMPANY—STORAGE OPERATIONS

The Peoples Natural Gas Company first started storage in May, 1937, in what was known as the Oakford storage area, located in Westmoreland County, Pennsylvania. This project was started as a means of conserving a large amount of excess gas which was available in northern Pennsylvania and southern New York from the prolific Oriskany pools which were at their peaks during the years of 1937 and 1938. Since that time, the Peoples Company has developed four additional storage pools, all of which are of the low-content, high-deliverability type, well adapted to meet peak-load conditions that characterize Peoples' markets during the winter months. The data on all of these pools are included in Table 3 and will be dwelt upon only briefly at this point.

The Oakford pool, which was the first pool used by any of the Consolidated companies for storage purposes, has been completely depleted of storage gas. The peak of storage was reached in November, 1938, at which time a total of 2.4 billion was stored in this pool. The last gas was withdrawn from the pool in January of the past winter, and it was recovered without any loss. As a matter of fact, the rock pressure of the pool after all storage gas had been withdrawn was slightly in excess of the pressure which prevailed before storage had taken place in the area. This does not mean, however, that any new gas was manufactured as a result of the storage project, but probably indicates a very slow migration of gas from the more isolated portions of the pool. Some of the increase in pressure has been due to a small amount of gas which migrated from a lower producing formation into the main storage zones. A cycle of input and withdrawal for the pool is shown in Figure 4.

The largest amount of gas stored to date in the four pools now actively oper-

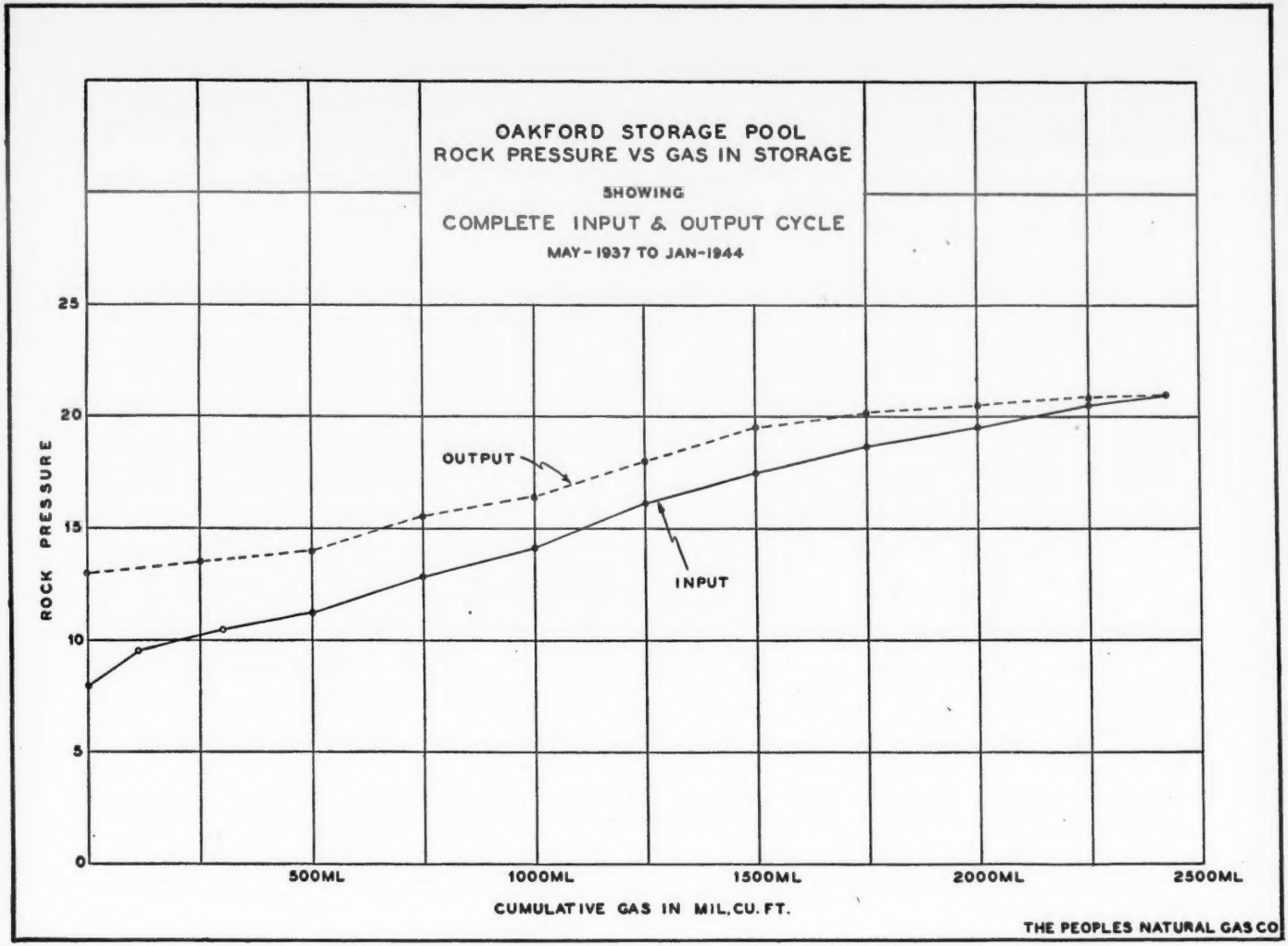

OAKFORD STORAGE POOL
ROCK PRESSURE VS GAS IN STORAGE
SHOWING
COMPLETE INPUT & OUTPUT CYCLE
MAY-1937 TO JAN-1944
ROCK PRESSURE
25
20
15
10
5
0
OUTPUT
INPUT
500ML
1000ML
1500ML
2000ML
2500ML
CUMULATIVE GAS IN MIL. CU. FT.
THE PEOPLES NATURAL GAS CO.

FIG. 4

ated by Peoples totaled approximately 3 billion cubic feet. At that time, only two of the pools were filled to the capacity at which it is the intent of the company to operate when sufficient gas is available. However, with this small amount of gas in storage, the company has been able to withdraw as much as 52 million cubic feet of gas per day on an intermittent withdrawal basis, and, during the past year, as much as 29 million cubic feet of gas per day on a steady withdrawal basis. There are only twenty-three wells in all of these pools, and the deliverability of several of the projects could be increased materially by the drilling of a few additional wells. With a "cushion" of less than 500 million cubic feet of storage gas in these four pools, the company has a minimum deliverability varying from 10 to 14 million per day. Any of the four pools will deliver 14 million per day for the first billion stored in it and 30 to 35 million per day with a storage of 2 billion to the pool.

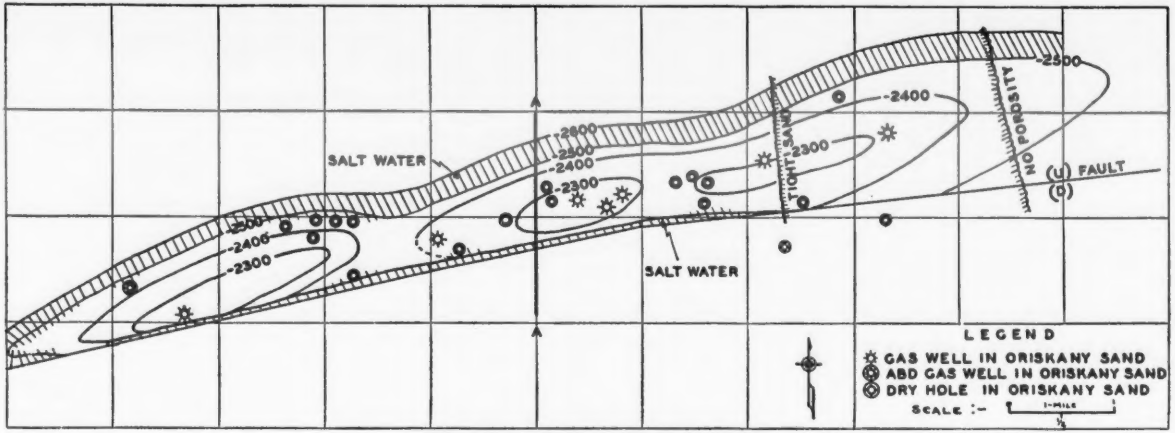
As storage pools go, these are probably ideal for the Appalachian area from the standpoint of the ratio of deliverability to gas stored. They are particularly well adapted for peak-load conditions, and because of the number of pools under operation, it is possible to use them on a steady withdrawal basis with equal success.

NEW YORK STATE NATURAL GAS CORPORATION—STORAGE OPERATIONS

FIG. 4

The New York State Natural Gas Corporation has one storage project, known as the East End Tioga (Boom) pool, located in Tioga County, Pennsylvania. This pool is unique among those belonging to the Consolidated companies, as it is the only storage project which has been developed in a former producing pool of the domal type (Figure 5). The pool was first discovered in 1930, and very large wells, some making as much as 35 million cubic feet open flow, were found in the Oriskany sand. Production from this gas pool was withdrawn very rapidly, and it was converted to storage by the New York State Natural Gas Corporation in July of 1940. Since that time, as much as 2,755,000 M c.f. of gas has been stored in the pool, with a corresponding rock pressure of 338 pounds. It required 9 million feet per pound of input to repressure this storage area. It is interesting to note that this is approximately the same amount of gas which was withdrawn per pound during the natural decline of the original gas pool (Fig. 6). During the past winter, this pool was used almost continuously, and as much as 25 million feet per day was withdrawn during the early winter. It has been possible to maintain a deliverability of as much as 20 million per day from storage under steady withdrawal conditions. In addition to supplying the excess requirements of the New York State Natural Gas Corporation during the past winter, a little over a billion feet was withdrawn from this pool to maintain the gas supply for war industries served by other companies in the northern Pennsylvania and western New York area.

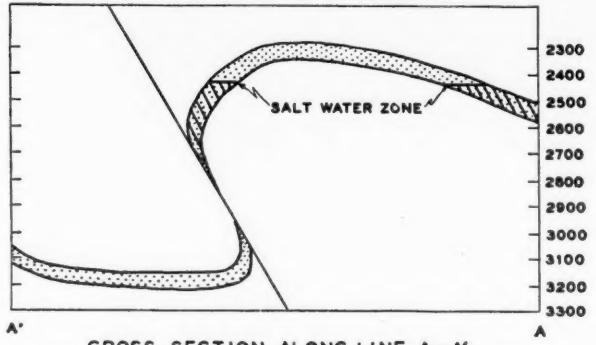
The total producing area in this pool is about 2,700 acres, and at present there are only five wells in the pool.



EAST END TIOGA STORAGE POOL

SHOWING

STRUCTURE ON THE ORISKANY SAND
AND THE LIMITS OF PRODUCTION



CROSS SECTION ALONG LINE A-A'

NEW YORK STATE NATURAL GAS CORP.

FIG. 5

FIG. 5

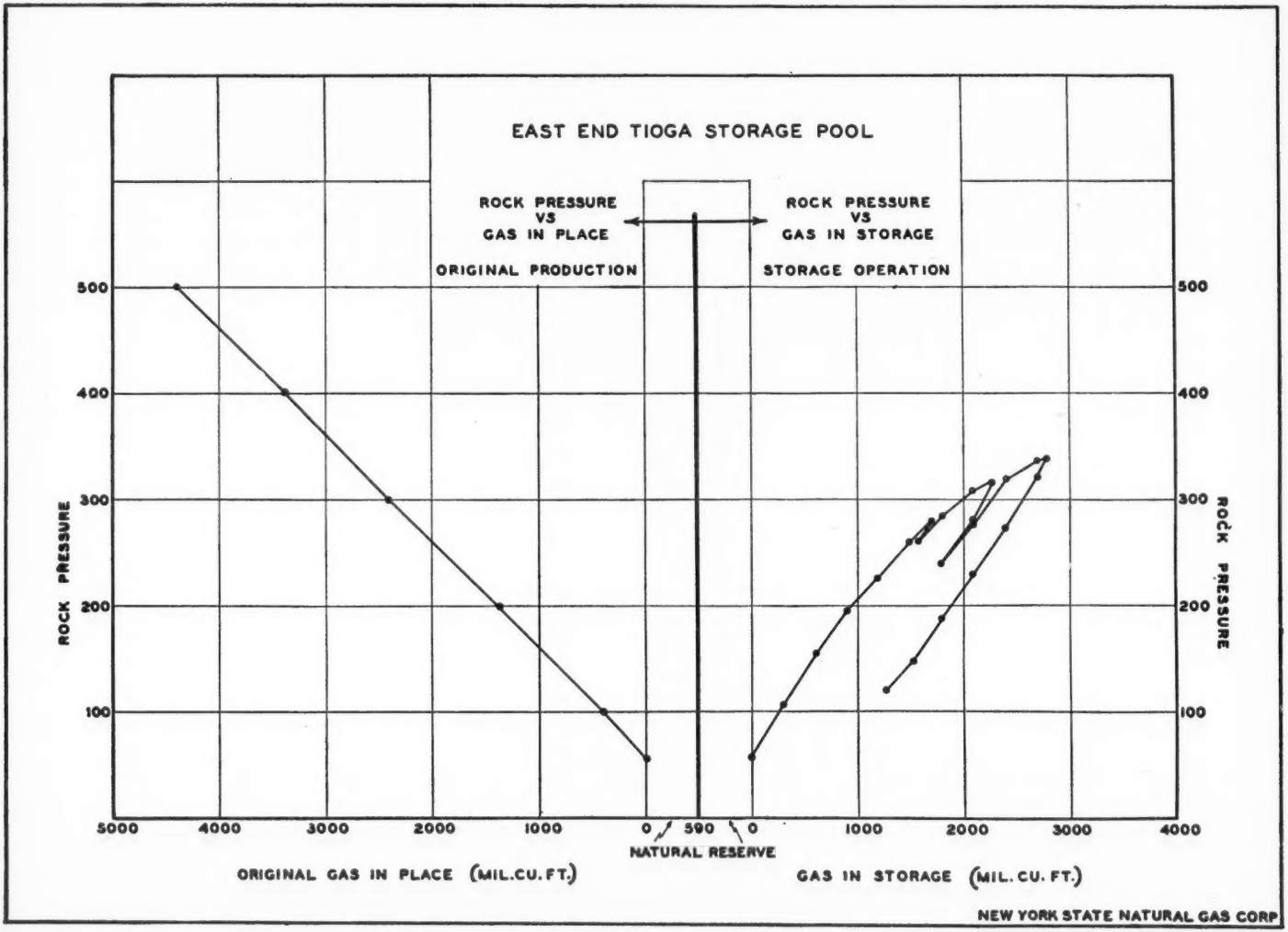
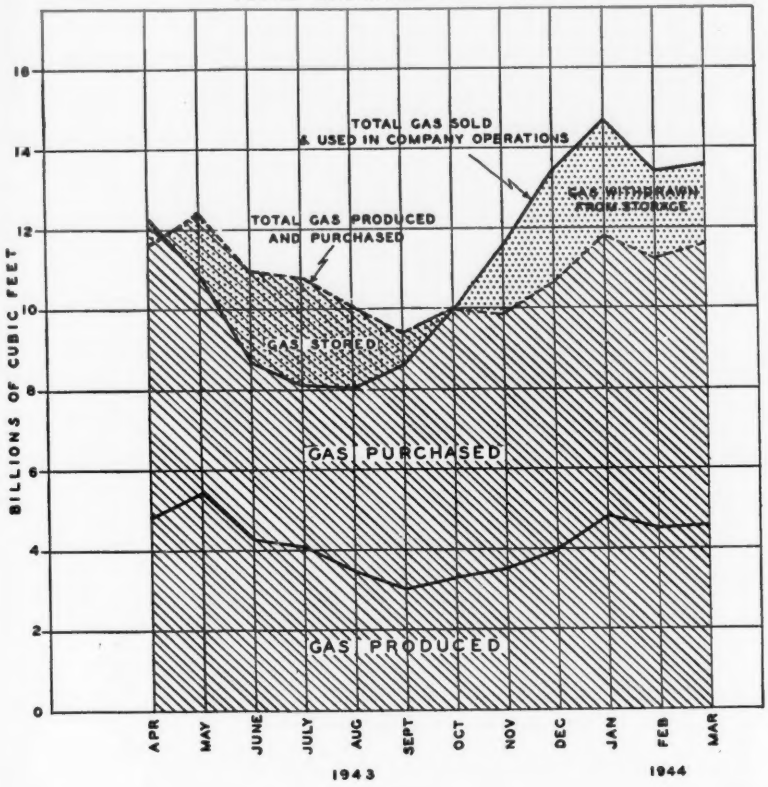

EAST END TIOGA STORAGE POOL
ROCK PRESSURE VS GAS IN PLACE
ORIGINAL PRODUCTION
ROCK PRESSURE VS GAS IN STORAGE
STORAGE OPERATION
ROCK PRESSURE
500
400
300
200
100
5000
4000
3000
2000
1000
0
590
0
1000
2000
3000
4000
NATURAL RESERVE
ORIGINAL GAS IN PLACE (MIL.CU.FT.)
GAS IN STORAGE (MIL.CU.FT.)
NEW YORK STATE NATURAL GAS CORP

FIG. 6

CONSOLIDATED NATURAL GAS COMPANY

STORAGE CYCLE - APR. 1 1943 TO APR. 1 1944
SHOWING BALANCING EFFECT OF STORAGE
BETWEEN
TOTAL GAS SALES AND SUPPLY



GRAPHS SHOWING EFFECT OF STORAGE
ON PEAK DAY & MINIMUM DAY
FOR
CONSOLIDATED NATURAL GAS CO. SYSTEM

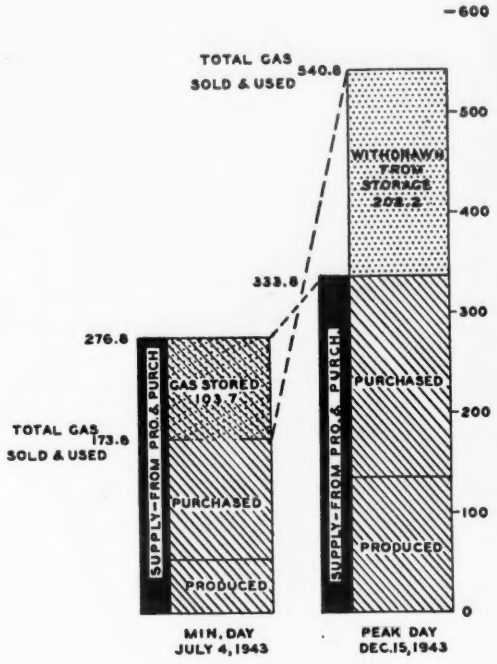


FIG. 7

Considerable information has been obtained from this storage operation, and it will be discussed in a later part of this report in connection with a review of some of the problems which arise as a result of storage undertakings. Figure 5 depicts the structure and size of the East End Tioga storage pool.

EFFECT OF STORAGE ON OPERATIONS OF CONSOLIDATED NATURAL GAS COMPANY

The cumulative effect of all storage pools belonging to subsidiaries of Consolidated is of great importance to the company's operations. During the year 1943, a total of approximately 12 billion feet of gas was injected into storage during off-peak periods, and approximately the same amount was withdrawn during the season of heavy output. As of the end of 1943, the company had a little over 21 billion feet of gas in storage available to meet the heavy withdrawal period, which occurs in the months of January, February, and March.

As will be noted from the above discussion, the company has all types and sizes of storage pools, and this diversification has been found of great importance, as it furnishes sufficient gas for long, steady withdrawals, as well as making it possible to have large amounts of gas available for peak days. The smaller pools, which have been selected because of the high porosity and permeability of the sands, provide large deliveries and are very important in meeting the peak-load problems of the company. The larger pools have enabled the company to maintain an auxiliary gas supply of considerable importance throughout the winter periods. Figure 7 indicates the leveling effect on Consolidated's sales and production. It will be noted that it is possible to store a great amount of gas during the summer months which would not be available during the winter, and that this gas, in turn, is withdrawn to meet the high demands during the winter.

FIG. 7

It is probably quite reasonable to say that Consolidated as a unit is able to sell at least 10 to 12 billion feet more gas per year as a result of storage operations than would be available without such facilities. However, the addition to sales is not nearly as important as the fact that storage has made it possible, even in these years of unusual demand, to maintain uninterrupted service to all of its consumers, except for very brief periods, despite heavy peak demands which develop during the winter months. Figure 8, showing the amount of gas produced and purchased and sales, together with storage by years from 1935 to the end of 1943, reveals the increasing importance from year to year of storage to the Consolidated system as a whole. The advantage to the company on peak and minimum days is apparent by a glance at Figure 7, which displays a typical peak day as compared with a minimum day and indicates the leveling effect of storage on the company's extremes of operation. It will be noted that there was an available supply of 104 million in excess of market requirements which was stored on a minimum day, and a total of 202 million was taken from storage on a peak day, to make up the difference between demand and normal supply. Without storage the difference between saleable supply on a minimum-day and peak-day

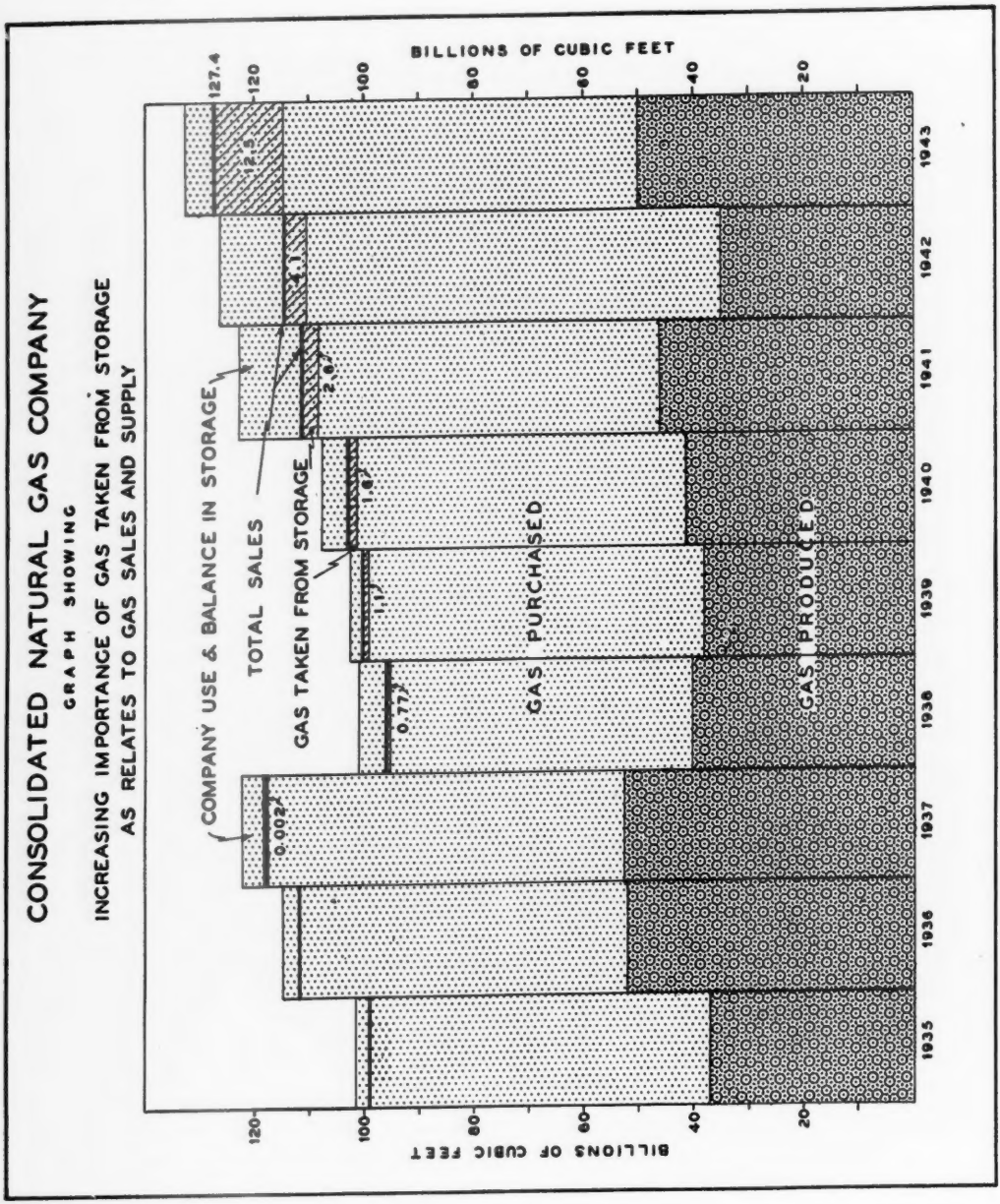

CONSOLIDATED NATURAL GAS COMPANY
GRAPH SHOWING
INCREASING IMPORTANCE OF GAS TAKEN FROM STORAGE
AS RELATES TO GAS SALES AND SUPPLY
BILLIONS OF CUBIC FEET
COMPANY USE & BALANCE IN STORAGE
TOTAL SALES
GAS TAKEN FROM STORAGE
GAS PURCHASED
GAS PRODUCED
127.4
12.5
2.1
2.6
1.8
1.1
0.77
0.002
1935
1936
1937
1938
1939
1940
1941
1942
1943

FIG. 8

demands would have been 368 million. By storage, this extreme has been reduced to 60 million. The peak day shown in Figure 7 is for December 15, 1943, the peak for the past winter. On that date, a reported 365 million was withdrawn from storage by all companies operating in the Appalachian area, and approximately 202 million of this impressive total came from pools operated by Consolidated.

The storage of natural gas is particularly vital to companies operating in the Appalachian area, as most of the production in this territory is from wells which are making less than 25 M c.f. per day, and it is necessary to produce these wells on a year-round basis, in order to make them pay for themselves. It is also a well known fact that the daily production from the entire Appalachian area is no longer adequate for daily demands during the winter months, but by gathering the production throughout the summer at its maximum rate and storing it, it has been possible to supply markets which would never have been maintained had it not been for storage.

Transmission of natural gas also has been favorably affected by storage, as it has been possible to move gas from centers of supply to storage pools in the vicinity of large markets and maintain the swollen demand of these markets without making additions to transmission lines. This has applied particularly to the New York State Natural Gas Corporation.

Storage will be of still greater importance to the Consolidated Natural Gas Company when recently made contracts for gas from Texas become operative. It will be possible to accept deliveries of gas from these western sources on an almost equal basis in both winter and summer.

The company also has benefited from a stability made possible by storage from the supply angle, since it has been possible to take gas from highly competitive areas where abundance had led to inefficient and uneconomical use and to store it during periods of over-supply for use at a later date, when the market demands were in excess of the supply. This particularly applies in the case of gas stored in the Oakford pool by the Peoples Natural Gas Company.

The cumulative picture of all storage projects controlled by the subsidiaries of Consolidated is shown in Table 5. Data on the Oakford storage pool and East Ohio's storage projects, known as Stark-Summit County Areas II, III, and IV, are not included in this table, because the Oakford pool is no longer used for storage, and the East Ohio pools above mentioned are in the testing phase only to date. A study of this table reveals that Consolidated has a total of 34,016 acres devoted to storage, involving the use of one hundred and sixty-six wells. The natural reserve (unproduced gas) of these pools is approximately 11 billion cubic feet, and, in order to insure a reasonable deliverability, an additional cushion of storage gas is required, equaling 7,424,000 M c.f. It is necessary to maintain this cushion of natural and storage gas at all times, and as long as the storage projects are in active use, this gas must be left in the ground. The minimum deliverability of all of these storage projects under the above conditions is 45 to 50 million cubic feet per day, and the maximum non-coincidental deliverability of all storage pools

FIG. 8

that has prevailed to date on a steady-withdrawal basis is 179 million cubic feet. The deliverability on an intermittent basis is much higher, being approximately 232 million cubic feet when the storage pools are filled. For short periods of a few hours' duration, deliverabilities are even higher than this latter figure.

During the most recent input and output cycles (April 1, 1943, to December 1, 1943, and December 1, 1943, to April 1, 1944, respectively), the total net amount of gas put into storage by the Consolidated companies was 6,266,641 M c.f., and the net amount withdrawn was 8,913,831 M c.f. Figure 7, which depicts monthly supply of gas produced and purchased, monthly sales, and storage input and output, displays the balancing effect between supply and demand that has been achieved by means of gas storage.

UNDERGROUND STORAGE PROBLEMS

1. PURPOSE OF PROJECT

If storage is contemplated by any company, it is essential to know the principal purpose for which the pool is to be used. If the problem which occasioned the need for a storage pool is one of peak load, it has been the experience of our company that it can best be solved by using pools which are small in area and possess the characteristics of good porosity and high permeability in the sands, which in turn result in high open flow wells. A pool of this type will furnish a high proportion of deliverability for the amount of gas stored.

Optimum delivery from a peak-load pool will be obtained if it is operated on a basis of frequent replenishment of gas withdrawn, or if operated under conditions which will permit its being "rested" as often as possible. If peak loads are apt to continue on a rather steady basis over an entire winter period, it is also essential that a good supply of gas be stored in order to maintain a fair deliverability over a long period of time. For a problem of this type, it is best to use a pool which will take at least 10 million per pound, as contrasted with pools requiring only 2 to 4 million per pound for the previously mentioned peak-load problem.

In the event that the storage pool is necessary because of large amounts of excess gas, which would depress the market and cause the gas to be used for uneconomical purposes, the larger pools are best, perhaps those requiring from 40 to 50 million feet per pound, similar to the Fink storage pool used by the Hope Natural Gas Company.

2. SELECTION OF STORAGE AREA

After the purpose of a storage project has been determined, the next problem to be solved is that of selecting a pool in which gas can be stored without having it drained beyond the limits of the property controlled by the company. This is strictly a geological problem, and no area should be selected without competent geological advice.

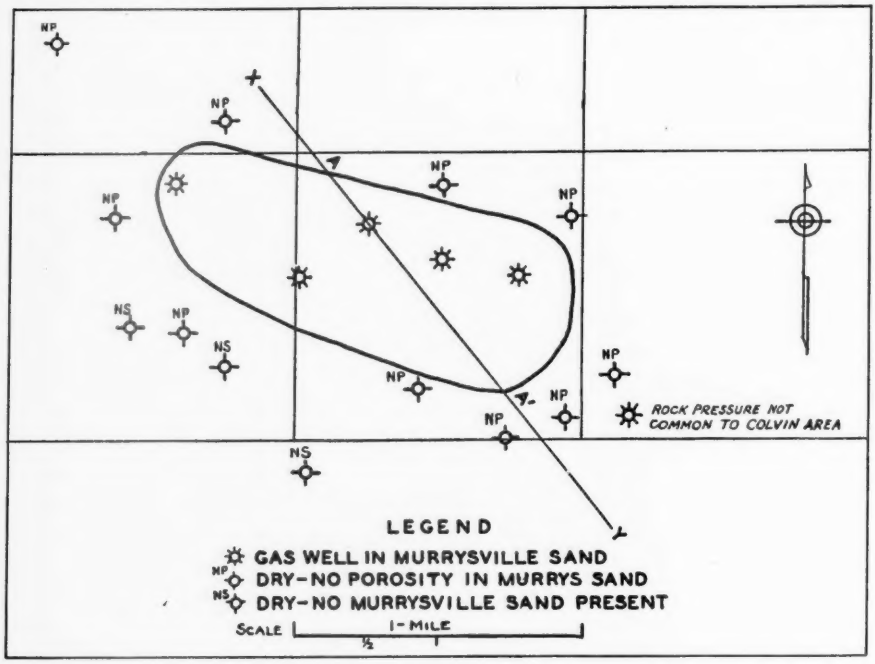
There are three geological types of pools that are adaptable for storage. In the Appalachian area, the "sand lens" or "porosity lens" type of accumulation in a

former gas pool which is to be used for storage is the most common. However, there are some closed structure or domal type pools available in the area. A third type is the multiple-sand pool. This differs from either of the other two only by the fact that more than one producing sand has been found in the same area. If this type of pool is to be used for storage, it is important that the limits of production of all sands are known and are under the control of the company contemplating storage.

The sand-lens or porosity-lens type of pool can be worked out by geological studies involving careful correlation of all well records in the area. It is also important to get the past history of every well in such a pool. In the Appalachian area, this often involves considerable research and talking with old drillers or with some of the older company employees who remember the characteristics of wells in the area which is being studied. It is important that the permeability of any gas pool which is to be used for storage be high and that the porosity also be relatively high. It is often possible to find a clue to an important storage pool by plotting the open flows of old wells throughout a large area. If a concentration of large open flow wells is found, a study may be made to determine the limits of the producing sand or the limits of porosity, and a favorable area for storage is sometimes revealed.

In selecting a porosity or sand-lens type of pool, it is necessary that all the data be plotted on a map similar to that shown in Figure 9, which depicts the Colvin storage pool controlled by The Peoples Natural Gas Company. It will be noted that the Murrysville sand is the producing sand in this pool. The limits of the pool were determined by carefully correlating all well records and plotting upon the map certain information concerning the presence or non-presence of the Murrysville sand, the porosity or non-porosity of the sand body, and the productivity or lack of productivity in the particular sand being studied. Original rock pressures were coördinated with time elapsed between the drilling dates of each well. After this was done, it was possible to outline the productive portion of the pool by drawing a line between the productive wells with a common rock pressure and all others which are either non-productive or have rock pressures not common to the pool, until this line described a closed area. It is vital, of course, that a rather large amount of former drilling should prevail in any area of this type before positive conclusions may be drawn.

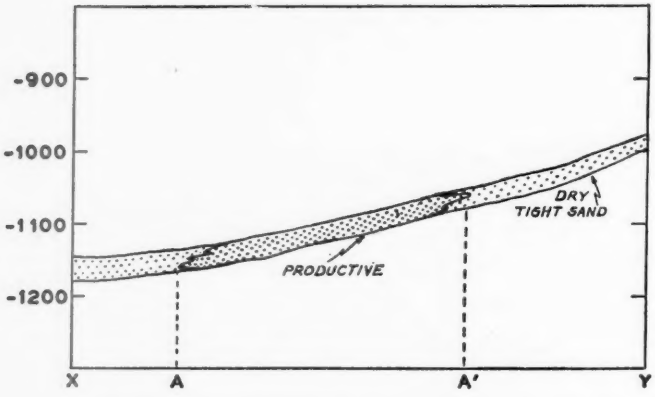
For the structure-type pool, it is necessary to study the subsurface information on the top of the producing horizon and to construct a structure map which will indicate the amount and direction of dip of the producing horizon within the productive limits of the old gas pool. This is a simple geological problem, and where many wells have been drilled, it is possible to define very closely the limits of this type of storage area. The map of the Tioga East End storage pool depicts a typical example of this type of accumulation. (For map of East End Tioga pool, see Figure 5.)



COLVIN STORAGE POOL

SHOWING

LIMITS OF PRODUCTION IN
THE MURRYSVILLE SAND



CROSS SECTION ALONG LINE X-Y

THE PEOPLES NATURAL GAS CO

FIG. 9

3. ACQUIRING RIGHT TO STORE GAS

After a storage pool has been worked out geologically, the next problem is to obtain storage rights throughout the area which will be affected by the gas that is to be injected. In most cases, this has been accomplished by effecting a modification of the former lease to give the company storage rights and in return paying the lessor an additional bonus or insuring him a long term lease. In the case of productive wells which are to be converted to storage wells, it has been found necessary to obtain the right from the lessor to use the wells for storage. In many cases, storage rights may be obtained by explaining the matter to him and showing him the advantages which he will derive because of the longer life of the wells. However, the company has found it necessary to increase the rental rate in many instances in order to obtain the lessor's consent. All of the storage projects belonging to Consolidated Natural Gas Company have a flat royalty rate for the wells, that is, so much per well per year, whether it is used or not.

Where other producing companies have wells or leaseholds in an area, it is necessary to acquire these properties. In most cases, this is not difficult to do, as the wells are commonly close to depletion, and the owners are glad to find an unexpected demand for a property which is no longer very profitable.

In the Appalachian area the major operating companies have been very coöperative and have frequently consented to an exchange of properties, which has resulted in one or the other party to the exchange acquiring control of an area suitable for storage.

4. RECONDITIONING PROBLEMS

After storage leases have been obtained, the pool must be reconditioned for the project. This may involve the drilling of new wells if there are not enough old wells which can be repaired in the area. Locations for such new wells should be made with geological advice, preferably by someone who has been familiar with the work done prior to selecting the pool for storage. There will be many old wells that will require repairs. It is necessary that the casing and fittings of all wells be sufficiently strong to withstand pressure from 100 to 200 pounds above the pressure at which gas will be stored in the pool.

In reconditioning old wells, it is not uncommon to find that the face of the producing sand has become clogged, as the result of long years of production. This may have taken place when water stood on the sand for a period of time or may be due to the tarry substances that commonly occur in gas reservoirs and in places are deposited on the face of the sand. Some wells may have become salted over and will need to be treated with fresh water.

Our company's experience in shooting old wells has been quite satisfactory. In some cases, we have found it necessary to sidetrack the hole somewhat above the producing sand and drill a new hole into the sand. For old wells that have been drilled prior to the time when accurate records were kept, it has been very helpful to verify the records with some temperature device in order to determine accurately the position of the pay horizons.

Many of the wells will require retubing or recasing, as the tubing or casing in the wells may be either too small to take care of the increase in production which will result from storage operation, or the pipe may have become defective from long years of usage. It also will be necessary to recondition or renew and sometimes enlarge all field lines within the storage pool between the booster storage station and the wells. There have been several instances where blowouts occurred which might have been avoided had the field lines been reconditioned or renewed prior to the beginning of storage operations. It is also very important that proper metering devices be installed, and it is believed to be advisable that several runs be installed for double checking the amount of gas put into storage and the amount of gas withdrawn from storage. Since gas is apt to be handled in very large quantities at times both during the input and output seasons, every possible precaution must be taken to get accurate measurements on the amount of gas stored and withdrawn. Temperature corrections should be made. Measuring stations should be situated far enough away from the pump stations to prevent errors in measurement due to pulsation.

In the early operation of a storage pool, many valuable data as to the performance of the pool and the characteristics of the various wells can be obtained if each input and output well has a meter on it and gas for each well is accurately measured. It is also important to have recording gauges on each well to determine the pressure at which gas is being stored or at which it is being withdrawn, and, also, to collect any information during off-storage periods on rock pressures.

If the storage pool which is being reconditioned has water in some portion of the sand, this need not necessarily condemn the area for storage. The Peoples Natural Gas Company has two storage pools in which some water is present. It has been found that by putting the gas in the dry wells (usually updip from the wet wells) and withdrawing gas from the wet wells, the water is gradually moved down the structure and out of the way. For the wet wells, it will be necessary to have large drip installations or separators in order to prevent water from getting into the main transmission lines when it is withdrawn. These problems are not difficult to overcome, and equipment of the type used in wet producing wells has been found adequate for wet storage wells.

5. METHOD OF INPUT AND OUTPUT

When the pool has been reconditioned for storage, it becomes necessary to decide on the method of input and output from the pool. In the larger pools, it is usually necessary to pump gas into storage and out; however, on many of the smaller peak-load type of pools, good results may be obtained by pumping gas into the storage pool and permitting it to flow out naturally during the output periods. This leaves the operation less susceptible to problems of defective equipment which might arise in the event that some of the pumps should break down during the output period. If the pool is not too large, it is definitely advantageous

to have the pumping operation take place almost entirely during the input cycle.

The whole problem of pumping is simplified if the storage pool is located in the vicinity of both high-pressure transmission lines and low-pressure lines which are relatively close to distribution points.

It is advisable to hold as much back pressure on a storage pool as is consistent with practical operations; that is, do not take the gas out without back pressure if sufficient gas can be obtained for the requirements by holding pressure on the output wells. Many gas pools have a water drive on the outside edge, and it is important to hold back pressure on any wells which are near the water line in order to prevent development of pressure gradients in the direction of the water and thus flood out the output gas wells.

6. DATA TO RECORD

In order to fully understand a storage pool, it is necessary to record many data on a monthly basis. Information on rock pressure of the pool, amount of gas put into storage, amount of gas withdrawn from storage, suction pressures, and output and input pressures should be recorded monthly and thoroughly analyzed at frequent periods during the early operations of storage pools. It is important to watch the amount of gas per pound on input and output, as this information will usually lead to the early discovery of any condition that had not been foreseen, such as having gas drained away from what was considered the main storage area, or it may lead to the early discovery of defective metering. As much information as possible should be gathered on the performance of each well in a storage pool in order that the production department may know which wells have characteristics which make them adaptable to either input or output.

7. CONDITIONING OF GAS FOR INPUT

It will be found advantageous to dehydrate any gas put into storage. This will eliminate the formation of hydrates during output, and will also permit a somewhat larger storage of gas in the sand without the danger of getting an undue concentration of water in some portions of the pool.

All gas put into storage should be cleaned. This is very important, as it may be seen that all of the gas must sieve through a relatively small area of sand face. If the gas is not thoroughly cleaned, there will be a collection of dirt deposits on the face of the sand which will affect the deliverability of the wells.

It goes without saying, of course, that adequate pipe-line and pumping facilities should be installed in order that gas may be produced freely from the storage pool at its highest rate of deliverability from the sand.

8. DELIVERABILITY DETERMINATIONS

One of the problems which continually reoccurs in connection with any storage project is the determination of deliverability of the storage area under

various conditions of pressure and amount of gas stored. It is quite apparent, of course, that the more gas stored in a pool, the higher the deliverability will be from the wells, since the increase in rock pressure of the pool is a function which largely controls deliverability. *In practically all storage pools, it is essential that a minimum amount of gas be left in storage at all times in order to maintain a deliverability high enough to make it an economical and advantageous project. The amount of gas necessary for a minimum of deliverability has come to be known by the industry as the "storage cushion."*

The factors which affect deliverability may be summarized as follows: (1) the facility with which gas can be moved from the wells into the pipe lines; (2) the number of output wells; (3) the amount of gas in storage; (4) the effective rock pressure of each output well. This last factor depends upon the coning effect around each well, that is, a zone of high pressure which develops around the well during input and a zone of low pressure which develops during output periods.

The effect of coning has been less understood than any other factor contributing to deliverability, and the failure to make proper allowance for it has been the chief reason for poor predictions as to future deliverability of a storage pool.

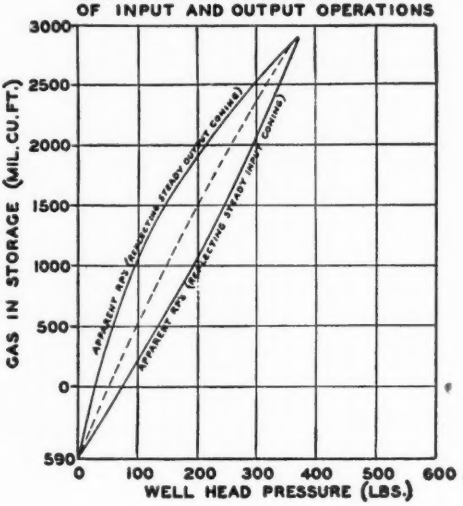
The coning effect differs widely from pool to pool; this, of course, is to be expected, as it reflects directly the over-all permeability and porosity of a storage pool. If the reservoir rock of a storage pool has uniformly high porosity and permeability, it will be much less affected by "coning" than a pool where the reverse is true. However, it is not necessarily a disadvantage. In fact, for peak-load pools, if gas can be restored at frequent intervals, it may serve to increase the ratio of deliverability to gas stored.

The wide variance in deliverability of a storage pool under conditions of steady withdrawal as compared with deliverability at times of intermittent withdrawal is due to this coning effect. For example, when gas is being withdrawn in large amounts, a low-pressure area will develop around each output well, and pressure gradients will exist around each well as this low-pressure area develops. Deliverability will be correspondingly decreased, despite the fact that there may be a large amount of gas in storage. The gas in storage does not readily flow through the sand from well to well, and because of this condition, gradients are bound to occur. Conversely, during input, there will be coning of high pressure around the wells, which tends to decrease the input rate of each well.

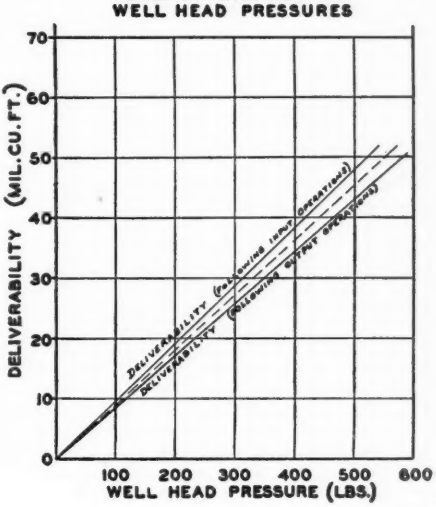
Our company has experimented with many types of deliverability curves, designed to determine the amount of gas that may be withdrawn from a storage pool. Figure 10, showing curves on the East End Tioga storage pool, illustrates those which have been found most satisfactory. Curves of this type, of course, are predicated on the assumption that adequate pipe-line and pump-station facilities have been installed to take the gas away from the wells at a rate that will not interfere with the deliverability of the wells under favorable back-pressure conditions at the well head. It is also recognized that deliverability could be increased by adding more output wells.

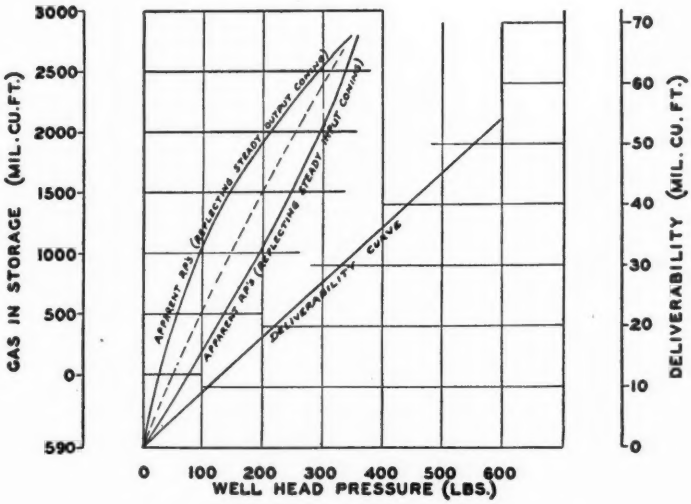
EAST END TIOGA STORAGE POOL

GRAPH SHOWING
CONING EFFECT ON ROCK PRESSURE
OF INPUT AND OUTPUT OPERATIONS



GRAPH SHOWING
DELIVERABILITIES VS
WELL HEAD PRESSURES





RELATIONSHIP BETWEEN
GAS IN STORAGE, WELL HEAD PRESSURE & DELIVERABILITIES
UNDER VARIOUS OPERATING CONDITIONS

NEW YORK STATE NATURAL GAS CORP

FIG. 10

The curve entitled "Rock Pressure Coning Effect vs. Gas in Storage" reflects the coning effect on rock pressure of input and output operations. This answer is obtained by plotting curves based on the amount of gas in storage against known well-head pressures at times when gas is being injected into storage and when it is being withdrawn from storage. It will be noted that steady-withdrawal conditions tend to depress the well-head pressures as compared with the true rock pressure, and that the reverse is true when gas is being injected into storage.

The curve entitled "Deliverabilities vs. Well-Head Pressures" is obtained by plotting two curves showing deliverability following input operations and deliberability following output operations. These curves are obtained by plotting known deliverabilities against known well-head pressures during (1) output operation, and (2) input operation. The average of these two curves is interpolated, and, for practical purposes, is considered the rate of deliverability under ideal conditions, that is, when the influence of coning is not a factor. It would be better to plot this latter curve direct, of course, but information necessary to plot it is seldom available.

By means of a third curve, which is a composite of the two above-described curves, it is possible to construct a set of curves by which deliverability can be determined which reflects the effect of the amount of gas in storage under the coning conditions which are typical of both input and output operations. The deliverability is always lower during steady output operations than it is following input operations. To read the curve, one may start from the lefthand side showing the amount of gas in storage, and by following the abscissa to its intersection with the curve reflecting coning on output and then following downward on this ordinate to the intersection with the deliverability curve and reading the abscissa to the right, the deliverability under steady withdrawal conditions can be obtained. The same process may be carried out, except that the curve showing coning during input operations is used instead of the output coning curve, to obtain a reading of deliverability following input conditions. Generally speaking, the reading obtained by using the output coning curve would apply in the case of a pool used more or less continuously to augment winter demands, whereas the other coning curve would apply best for deliverabilities on a curve for a pool used only occasionally to meet extreme peaks.

It will be noted that the curve shown indicates practically a straight line for deliverability. This will not apply to many pools where permeability and porosity are low.

These curves, while solving the problems of one pool, do not give the complete answer to the deliverability question and are given here only as one approach to the problem.

9. ECONOMIC PROBLEMS

Storage is still relatively new to the industry, and apparently there is no standard accounting practice used by all of the gas companies. Our own company

has priced the gas put into storage at an average cost of gas being purchased during any one month of input. When the gas is withdrawn from storage, it has been priced at the average cost of all gas in the particular storage pool from which the gas is withdrawn. This method, undoubtedly, would not be applicable to all companies. It would be particularly difficult for a company which produced a very large share of its gas and purchased only a small amount, perhaps a smaller amount than is being put into storage.

To date, storage may still be classed as being in the development stage. Consequently, it is not possible to obtain an accurate cost on an M c.f. basis. It is quite obvious that the more gas stored and withdrawn in a short period, the less the cost of storage. Since complete data are not yet available, our company has not attempted to make a thorough study of storage costs. However, it would appear from a study of some of the factors that the approximate partial cost varies from $.03 to $.12 per M c.f. These figures make no allowance for return on the investment of equipment used in connection with storage, no allowance for overhead, and no allowance for the amount of gas required for cushion in order to insure minimum practical deliverabilities. The proportionate share of the cost for input and output is roughly the same. It should be borne in mind, however, that these figures represent only the cost of labor, maintenance, supplies, expenses, and rents.

It may be seen from these very rough figures that storage is an expensive luxury and can not be carried on too extensively, as it will have a depressing effect on any company's earnings.

Some arrangement must be made to provide for a return on the investment in the amount of gas left in storage at all times as a cushion. Whether the method should be one whereby the cost of such cushion gas would be placed in plant inventory or whether it should be added to working capital is a question for the industry at large to decide.

SUMMARY AND CONCLUSIONS

From the experiences with storage of the subsidiaries of the Consolidated Natural Gas Company, there are certain salient facts which can be brought out. It is not practical to use too large a pool for storage purposes unless large quantities of excess gas, which otherwise might be sold at distress prices, are available. Small pools containing not over 2 or 3 billion feet of gas at 500 pounds restored pressure are much more adaptable for peak-load conditions, since it is possible to obtain high deliverability from this type of pool with a minimum of gas tied up in permanent cushion. Medium-sized pools requiring from 10 to 20 million per pound build-up are best for a combination of peak-load and steady-withdrawal conditions. As a rule-of-thumb, it may be said that any storage pool which will yield a deliverability of 5 million per day per billion stored on the first 2 billion is very satisfactory and will provide a maximum amount of recycling of output and input in the course of one year.

Old depleted gas pools in the Appalachian area may be found suitable for storage throughout the producing formations of the geological section. The Consolidated Natural Gas Company has pools in formations belonging to the Mississipian age and ranging down to and including the Clinton formation of Silurian age. If porosity and permeability conditions are satisfactory, there seems to be no limiting factor in the geological column.

The best geological advice obtainable should be secured to investigate an area which is being planned for storage.

It has been our experience that storage rights should be obtained from all lessors within a storage area, and it is more satisfactory to obtain the right to use wells for storage on a yearly rental basis, rather than on a royalty basis.

Reconditioning problems for storage pools are very similar to those which face the industry in connection with upkeep on their producing wells. Any pool in which storage is contemplated should have all lines, well fixtures, and casing renewed and conditioned to stand pressures materially in excess of the contemplated highest restored pressure of the storage pool. Metering facilities should be of the best, and it will be found both economical and wise to have several meter runs to "double check" the amount of gas stored and withdrawn.

Future predictions of deliverabilities of any proposed storage pool should be accepted with considerable caution, until data obtained from actual testing of the pool are available, and it is very important to bear in mind that pressure gradients will materially affect the amount of gas which can be withdrawn under steady-withdrawal conditions. No estimate should be made for future deliverabilities which is based on intermittent-withdrawal conditions if the pool is to be used on a steady-withdrawal basis.

In order to maintain deliverability at a high enough rate to make the storage operation economical, it is essential that a certain minimum amount of gas, known as "cushion," be left in a storage pool from year to year.

Some oil or water in wells within a proposed storage pool should not prove a deterrent to using the pool for storage, because under proper operating conditions their presence does not represent a serious handicap.

It is best to inject dehydrated and clean gas into any storage pool in order to do away with the trouble accompanying the formation of hydrates and in order to keep the face of the sand as clean as possible, as any dirt in the face of the sand will materially decrease the deliverability of a storage pool.

If possible, it is wise to locate a storage pool near high-pressure transmission lines and low-pressure lines leading to centers of distribution. Less energy will be required for pumping when the pool is thus located. If possible, the most satisfactory operations may be obtained by pumping most of the gas into storage and using pumps only in the last part of the cycle of output.

A large, rather than small, number of wells in any proposed storage pool will result in better operating conditions, provided that other things, such as good porosity, permeability, and control of the drainage area, are present.

In conclusion, it may be said that storage of natural gas has proved itself to be a new and valuable tool to the gas industry. It is, perhaps, the most significant operation that has been added to our industry in the past 20 years, as it seems to provide in large measure the flywheel which was needed to balance the difference between supply and demand which exists on both a daily and seasonal basis and which has long been one of the serious problems of the industry. However, the storage of natural gas is an expensive operation and is bound to add to the cost of getting gas to the consumer and, therefore, should be used only in those cases where the balance between supply and demand can not be corrected by a cheaper method.

The industry must also accept the fact that storage is not a "cure-all" and that the problem of over-all supply is only temporarily alleviated by storage. There is still only one method of providing a steady supply for many years and that is by drilling new wells for production, whether these wells be located in the Appalachian region or in more distant provinces.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1596-1625, 4 FIGS.

UPPER PERMIAN OCHOA SERIES OF DELAWARE BASIN, WEST TEXAS AND SOUTHEASTERN NEW MEXICO[1]

JOHN EMERY ADAMS[2]
Carlsbad, New Mexico

ABSTRACT

The Ochoa series includes the uppermost Permian deposits of the southwestern United States. Most of the rocks included in the series are poorly exposed unfossiliferous evaporites. The well known subsurface section in and around the Delaware basin is described and illustrated by cross sections. A short chapter discusses theories on the origin and distribution of the characteristic evaporites.

INTRODUCTION

The Permian rocks of the Delaware basin and its bordering uplifts, in West Texas and southeastern New Mexico, have been selected as the standard Permian section for North America.[3] In this basin the system is subdivided into four series, named in ascending order Wolfcamp, Leonard, Guadalupe, and Ochoa. The type sections of the first three are well known, easily accessible, well exposed, highly fossiliferous, adequately described, conventional surface sections. The Ochoa series, on the other hand, is practically non-fossiliferous, many of the beds are not exposed, and the anomalous outcrops of the others are poorly exposed and inadequately described. For these reasons, the representative subsurface section of the Delaware basin, where the series is best developed, was taken as the type. The substitution of a subsurface for a conventional surface type section was further justified because the fully developed Delaware basin section is well known to the many geologists in the area. The present paper is designed to supplement previous publications and present a more nearly comprehensive picture of the type Ochoa.

For those unfamiliar with the area, King's recent description of the Permian stratigraphy and sedimentation is recommended as a background.[4]

DELAWARE BASIN

Delaware basin is the name applied to one of the most negative segments of the Permian basin. As shown on the map (Fig. 1), it is an irregularly pear-shaped depression occupying parts of West Texas and southeastern New Mexico. The

[1] Manuscript received, September 9, 1944.

[2] Geologist, Standard Oil Company of Texas. The writer is indebted to E. Russell Lloyd, Robert L. Bates, Ronald K. DeFord, John M. Hills, Ralph King, Robert E. King, Walter B. Lang, the late George A. Kroenlein, R. D. White, and a host of others who have read and criticized the manuscript or have assisted with original ideas. Data are from the files of the Standard Oil Company of Texas.

[3] John Emery Adams, M. G. Cheney, Ronald K. DeFord, Robert I. Dickey, Carl O. Dunbar, John M. Hills, Robert E. King, E. Russell Lloyd, A. K. Miller, C. E. Needham, "Standard Permian Section of North America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1673-81.
C. W. Tomlinson, Raymond C. Moore, Robert H. Dott, M. G. Cheney, John Emery Adams, "Classification of Permian Rocks," *ibid.*, Vol. 24 (1940), pp. 337-58.

[4] Philip B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), pp. 533-763.

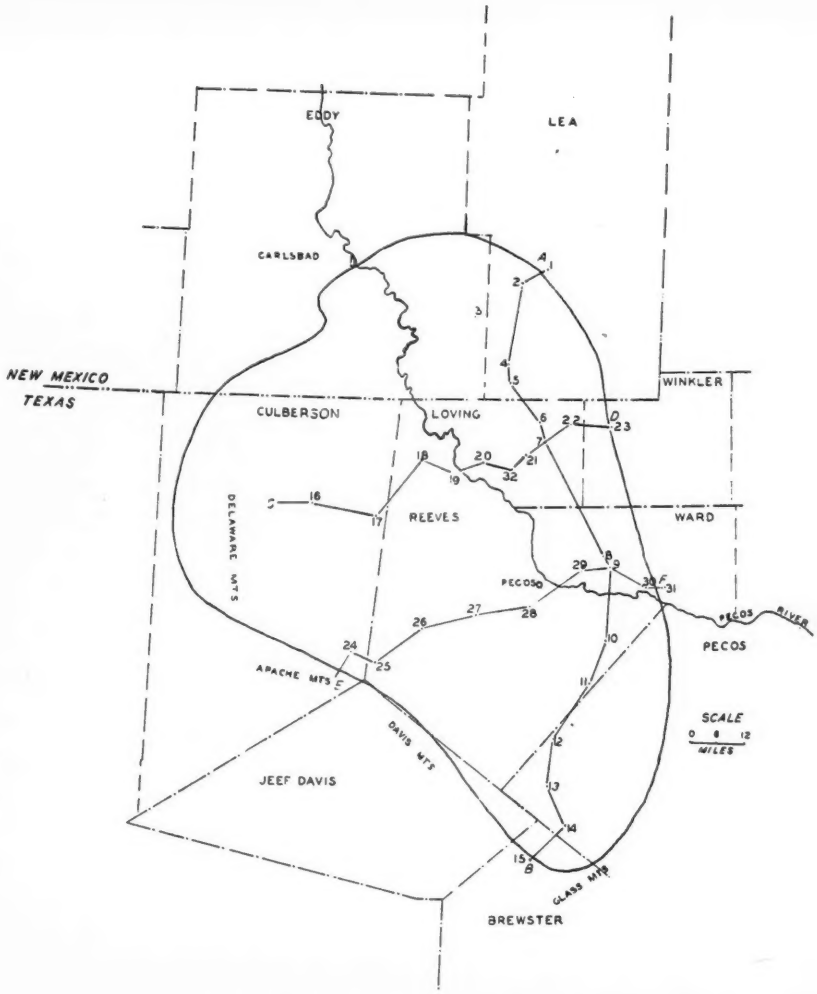


FIG. 1.—Outline map of Delaware basin with traces of cross sections.

Index of Wells Used in Cross Sections

1. Humble No. 1 Saunders
2. Masco No. 2 Cloyd
3. Marland No. 1 Gardner
4. Marland No. 1 King
5. Homestead No. 1 Clifford
6. Whiteside No. 1 Fee
7. Pinal Dome No. 1 Means
8. Slack No. 1 Hayes
9. Fitzpatrick No. 1 Dier
10. Brooks No. 1 Eddins
11. Penn No. 1 Bowles
12. Dixie No. 1 Hershenson
13. Humble No. 1 Gray
14. Humble No. 1 Kokernot
15. Dodson No. 1 Texas American Syndicate
16. Niehaus No. 1 Caldwell
17. Plymouth No. 1 Derrick
18. Grisham & Hunter No. 1 T. P. Land
19. Humble No. 1-B Kloh
20. Humble No. 1-C Kloh
21. Owens & Sloan No. 1 Johnson
22. Kingwood No. 1 Moore
23. White Eagle No. 1 Leck
24. Deep Rock No. 1 Kloh
25. Deep Rock No. 1 Tatum
26. Hill No. 1 Ely
27. Gaines & Melton No. 1 Patterson
28. Humble No. 1 Balmorhea
29. Plains No. 1 McGregor
30. Owens No. 1 Johnson
31. Kugle No. 1 Keasler
32. Dixie-Phillips No. 1 Johnson

The north-south length is approximately 165 miles and the east-west width 96 miles. Initiated early in the period, recurrent subsidence allowed the Delaware synclinal depression to receive and preserve the most nearly complete section of Permian rocks in the whole Permian Basin province. Throughout its early history, the Delaware basin was the site of pontic[5] (deep-water, marine, clastic) deposition. Typically pontic sediments consisting of black limestones, dark shales and silts, and fine sands accumulated to a thickness exceeding 7,500 feet. The bowl-like depression in which these beds are preserved was outlined by limestone reefs built along the margins of the surrounding shallow carbonate-depositing shelf seas. The system of pontic marine basins, reefs, and shelf-sea platforms reached its climax with the close of Guadalupian sedimentation.

Topographically, at the inception of the Ochoan epoch, the Delaware basin was an unfilled, geosynclinal bowl averaging approximately 1,700 feet in depth and encircled by steep-faced, cliff-like reefs between 1,200 and 2,000 feet high. Stratigraphically, it was underlain by a light sedimentary column of sands and shales in contrast to the heavy, massive limestone sections underlying the surrounding high, positive areas which stood at or just above sea-level.

STRATIGRAPHIC SUMMARY

The early Ochoa sediments are limited to the Delaware basin depression. They parallel the underlying beds in the center of the basin and butt against the Capitan reef face along the margins. When the basin was pracically filled, regional subsidence allowed the sea to climb out of the restricted depression and spread widely over the southern Permian basin. Thus the Ochoa rests unconformably on the upper surface of the Guadalupian sediments everywhere except in the Delaware basin. The absence of deep or extensive truncation or solution of the readily soluble rocks on the exposed platforms surrounding the basin before their burial by the general advance of the sea in mid-Ochoa time indicates a very slow rate of erosion and a relatively slight age differentiation.

The upper Guadalupian sediments of the Delaware basin, consisting of marine sands, dark shales, and limestones, contrast sharply with the light-colored evaporites of the overlying Ochoa. This marked lithologic change is the sharpest and most easily recognized stratigraphic break in the Permian section. Like all other reference horizons in the Ochoa, it can be more easily recognized in wells than in the normal, poorly exposed outcrops.

The change from marine to evaporite deposition was caused by the partial cutting-off of the channel or channels through which the unconcentrated sea water had previously been drawn into the basin. Chemical precipitation of evaporites followed shutting-off of free circulation. The close structural conformity between the Ochoan and Guadalupian deposits in the Delaware basin itself and on the surrounding shelf-sea areas would be most simply explained if

[5] E. Russell Lloyd, "Theory of Reef Barriers," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 22 (1938), p. 1709.

the seaway were silted up or blocked by post-Capitan reef growths without accompanying diastrophism.

The Ochoa sediments are divided into four formations named from the base upward, Castile, Salado, Rustler, and Dewey Lake. The Rustler and Dewey Lake are distinct, easily differentiated formations. The standing of the two lower formations has been questioned and even at present the dividing horizon can not everywhere be recognized.

For many years this section of evaporites was classed as undifferentiated Castile. Cartwright,[6] recognizing that the lower part differed from the upper not only in lithologic character but also in distribution, divided the section into two formations called "Upper Castile" and "Lower Castile." The "Lower Castile," in the usage of the time, was intended to include that part of the Ochoa section limited to the Delaware basin. From the very incomplete information available, it was generally assumed that the top of the calcite-banded anhydrite in the lower part of the evaporite sequence was a definite horizon corresponding closely with the base of the anhydrite member, now called the Fletcher anhydrite, on top of the enclosing reef; thus, the "Lower Castile" was commonly considered as the zone of banded anhydrites.

Lang, realizing that if there were two formations present, their designation as "Upper Castile" and "Lower Castile" was inconsistent with good stratigraphic nomenclature, restricted the name Castile to the lower part of the pre-Rustler section and introduced the name Salado halite for the upper part.[7] His separation of the two formations was based originally on the presence or absence of potash and the Salado halite was defined to include all pre-Rustler evaporites containing more than 0.5 of 1 per cent of potash. The base of the formation, according to this definition, was determined at 2,350 feet in the Pinal Dome's Means well No. 1 in eastern Loving County, Texas. This subdivision met with some criticism. The separation of two geological formations on the basis of quantitative chemical tests was not accepted by geologists not qualified or equipped to make such tests. Furthermore, it had become apparent not only that the top of the banded anhydrite was not a constant horizon, but that the base of the potash salt also moves up and down the geologic column. It was recognized that the fluctuating base of the potash neither corresponded with the main stratigraphic break in the section nor limited the Castile formation, so defined, to the Delaware basin.

These valid objections led Lang to extend the Salado halite to include equivalents of all the beds extending across the reef rim.[8] The thin bed of anhydrite between the top of the Capitan reef and the base of the salt in the reef and back-reef areas, for which he later proposed the name Fletcher anhydrite, was

[6] Lon D. Cartwright, Jr., "Transverse Section of Permian Basin, West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 969–81.

[7] W. B. Lang, "Upper Permian Formations of Delaware Basin of Texas and New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19 (1935), pp. 262–70.

[8] W. B. Lang, "Salado Formation of Permian Basin," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1569–72.

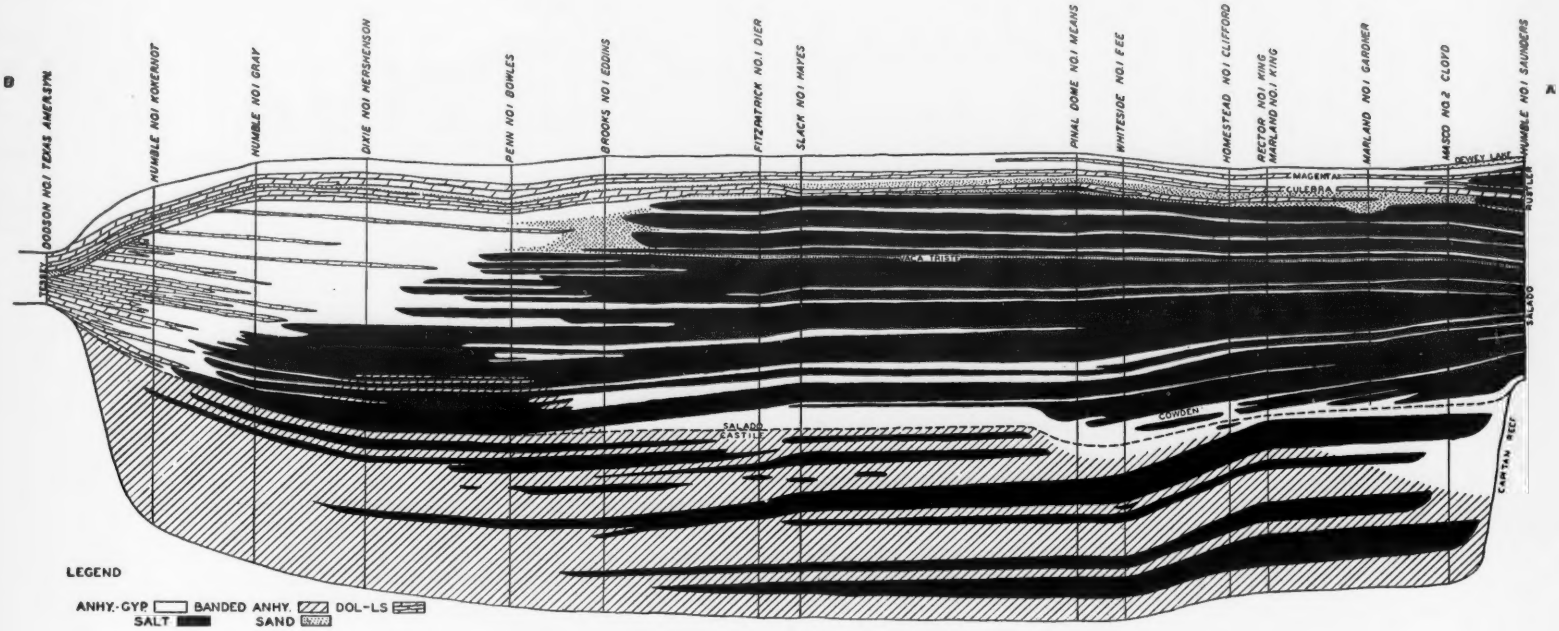


FIG. 2.—Diagrammatic south-north section (BA) of Ochoa rocks in Delaware basin. Line of section shown in Figure 1.

made the basal member of the Salado formation. By this definition, which is generally accepted, the Castile formation is limited to the Delaware basin. The unsupported definition, however, gives only a partial picture of the conditions. The writer believes, as indicated on the accompanying stratigraphic sections, that there is a natural structural and stratigraphic basis for dividing the pre-Rustler, Ochoa evaporites into two distinct formations that can be recognized in the center as well as along the margins of the Delaware basin.

Most of the redbeds of the Delaware basin previously classed as Permian[9] belong in the Triassic Pierce Canyon formation. Uppermost Permian redbeds, present in a few localities, are assigned to the Dewey Lake formation.

The outcropping Pierce Canyon redbeds of the Pecos Valley are similar lithologically to the post-Dewey Lake redbeds of the southern Permian basin and to the Quartermaster of the Panhandle. They occupy the same position with respect to the Upper Triassic Santa Rosa sandstone and, judged by the sections encountered in thousands of intervening wells, form a continuous stratigraphic unit. Regionally these redbeds overlap a wide range of Permian formations. In some localities the basal unconformity is overlooked and they are classed as Permian. They are made up largely of reworked Permian sediments with admixtures of new minerals, including coarse, rounded, but unfrosted, red quartz sand grains.

Arthur Morgan[10] of the United States Geological Survey, who studied the water resources of the area, reports that in closely spaced core tests, in central Eddy County, New Mexico, these redbeds can be shown to rest unconformably on the eroded upper surfaces of the Rustler anhydrite. R. W. Richards[11] who has recently mapped the surface geology for the United States Geological Survey, says, "I believe that the unconformity between the pre-Gatuña redbeds which Lang called Pierce Canyon and the Rustler can be found exposed in many localities east and southeast of Carlsbad."

These redbeds may be Permian in age, but judged by the lithologic dissimilarity from the underlying Permian and the evidence of local and regional unconformities, they are more probably Triassic. If they are Permian they were not deposited until the older Permian sediments had been warped and truncated. So far no conclusive proof of their Permian age has been presented.

STRATIGRAPHIC SECTIONS

The clearest way to present stratigraphic data is by use of diagrams (Figs. 2, 3, 4). Details can best be shown on simple cross sections. Since there are no

[9] W. B. Lang, *op. cit.* (1935).
John Emery Adams, "Oil Pool of Open Reservoir Type," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20 (1936), pp. 780–96.
Ronald K. DeFord, N. H. Wills, C. D. Riggs, "Fall Field Trip, Eddy County, New Mexico," *West Texas Geol. Soc. Guidebook* (1940), pp. 2, 4, 17.
Ronald K. DeFord, "Editorial Note," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (1942), p. 613.

[10] Arthur Morgan, personal communication.

[11] R. W. Richards, personal communication.

measured surface sections of any of the Ochoa formations except the Rustler, the number and locations of possible cross sections, in the Delaware basin, is controlled by the distribution of suitable wells. The sections shown do not duplicate

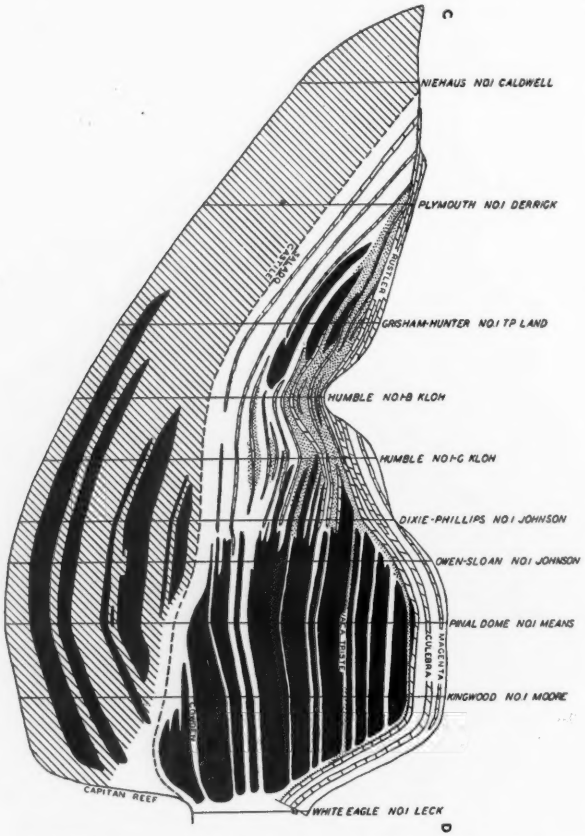


FIG. 3.—Diagrammatic west-east section (CD) of Ochoa rocks in Delaware basin. Line of section shown in Figure 1.

any previously published. The most dependable well logs available are those made from microscopic examinations of complete sets of carefully collected cable-tool cuttings. Most of the logs used in the sections belong in this group. Core data from critical parts of the section, in a few wells, are included. A few of the sample logs are from rotary wells. Information from drillers' logs and logs of adjacent wells was used to supplement the sample descriptions of the wells shown. Since the purpose of the writer is to present stratigraphic rather than structural in-

formation, generalized diagrammatic sections are shown. Elevations were largely disregarded and the well sections were balanced against each other in an attempt to reproduce, as nearly as possible, structural conditions near the close of Permian

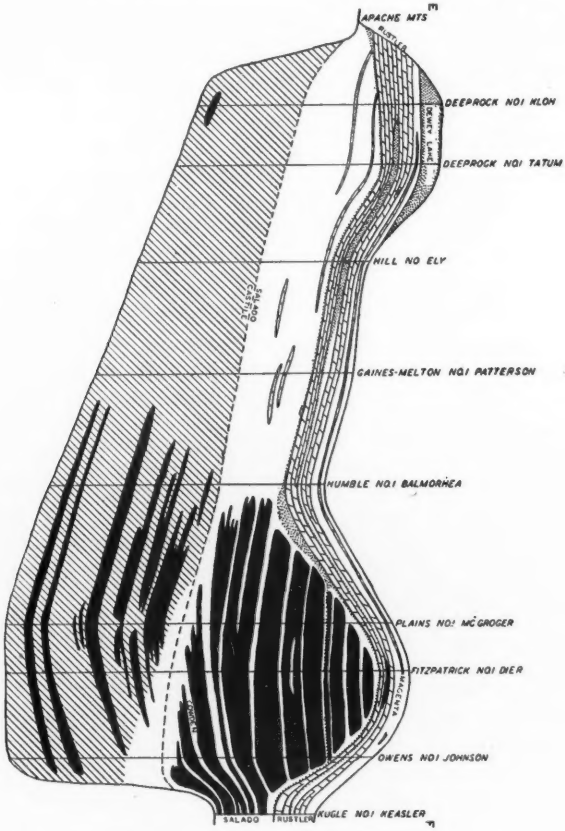


FIG. 4.—Diagrammatic west-east section (EF) of Ochoa rocks in Delaware basin. Line of section shown in Figure 1.

sedimentation. On the scale used, it was impossible to show all the minor details and gradations of stratigraphy.

CASTILE FORMATION

The Castile, the basal formation of the Ochoa series, is composed of anhydrite, calcite-banded anhydrite, salt, limestone, minor amounts of other evaporites, and minute quantities of very fine clastics. No potash salts have been reported. In the Castile, as in all other Permian formations of the area, the calcium sulphate

of the outcrops and of subsurface sections to a depth of about 500 feet tends to be gypsum. Beds buried to a greater depth are almost everywhere anhydrite. Throughout this paper the term anhydrite is used for both except when a distinction is to be made.

The Castile formation, which is limited to the Delaware basin, has an average thickness between 1,500 and 1,850 feet, but in west-central Ward County it reaches a maximum of more than 2,100 feet. Calcite-banded anhydrite, the main constituent of the Castile section, is made up of alternating bands or laminae of calcite and anhydrite. In most of the calcite laminae there is enough bituminous material to stain the carbonate a deep brown. The sharp color contrast between these brown sheets and the interlaminated white anhydrite stimulates curiosity. A residue of deep brown bituminous flakes remains to mark the parting when the calcite is digested in acid. Even where the calcite is missing, brown organic bands are present along the bedding planes of the anhydrite. The bituminous material, however, is nowhere mixed with the white anhydrite as it is with the calcite. Probably the bituminous flakes will yield recognizable organic remains, similar to those found in oils, when examined with sufficiently high magnification.

There are almost unlimited variations in the character of the banding. Where evenly developed, the laminae resemble chemical varves with the anhydrite layers two or three times as thick as the calcite. Udden makes the quite logical suggestion that the regular laminae represent annual cycles of sedimentation.[12] Individual carbonate partings range from scattered calcite crystals on the anhydrite bedding planes to beds of thinly laminated limestone several feet thick. The limestones are not dolomitic. The average thickness of the calcite laminae appears to be about $\frac{1}{20}$ inch. Thin sections show that the thinnest laminae are made up of one layer of coarsely crystalline calcite, and that the thicker beds are coarsely granular limestone.

Irregularly distributed through the normal banded zones are beds of unlaminated anhydrite, ranging from $\frac{1}{2}$ inch to several feet in thickness, and separated by banded zones that vary even more widely. There is a tendency for secondary calcite crystals to develop in fractures and in wavy ghostlike bands or even sprinkled about at irregular intervals, through these thicker anhydrites. The secondary calcite is almost everywhere lighter-colored than that of the normal laminae.

A thick calcite band is to be expected immediately above each thick anhydrite member. However, it seems that the anhydrite bed has to be three or four times as thick as the regular anhydrite laminae before any corresponding calcite cap develops. The sequence is not invariable. Some over-thickened anhydrites seem to have no corresponding cap, and even where the cap is exceptionally thick it may be separated from the thick anhydrite zone by one more or less normal, but commonly paper-thin, calcite lamina. The arrangement is sufficiently constant, how-

[12] J. A. Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. America*, Vol. 35 (1924), pp. 347–54.

ever, to be used in orienting random cores and surface blocks. In the rare instances where the calcite cap of one thick anhydrite is followed immediately by another thick unbanded anhydrite zone, the gradation is less sharp at the top of the cap than at the base. Everywhere that thick carbonate caps have been noted, they are made up of thin calcite laminae rather than of massive or thick-bedded limestone layers. A one-foot limestone may have four or five hundred of these almost microscopic laminae. From present limited information we can not be certain that these unbanded, thick anhydrite beds and their thick calcite caps are of basin-wide distribution. Some individual calcite-cap zones have been followed for more than a mile along the outcrop only to be lost where the beds pass under a cover of soil. Since there are thick unbanded zones in the south as well as in the north end of the basin, it is assumed that the beds are continuous.

As shown on the stratigraphic sections, the top of the calcite-banded anhydrite does not mark a time-stratigraphic horizon. It extends several hundred feet up into the basal Salado in the south-central part of the basin and sinks approximately 800 feet below the top of the Castile near the northeast rim. The thickness and prominence of the calcite laminae also vary across the basin. The thickest limestone beds appear to be at or near the base of the formation in the southern and western areas, but some central basin wells show as much as 25–30 per cent calcite in cuttings and cores through hundreds of feet of section. Near the top of the banded zone the calcite partings decrease in number and thickness, but the change from prominently laminated to unbanded anhydrite is gradual and may occupy hundreds of feet. Wells in the northeast part of the basin show relatively lean banding throughout the entire laminated zone.

On the outcrops in the Delaware Mountains, the thin calcite laminae of the northern exposures appear to thicken southward, and along Paint Horse Draw, in central Culberson County, those of the basal Castile coalesce to form beds of granular gray limestone. Interspersed through these granular beds are zones of thinly laminated, bituminous calcite, similar in appearance to the calcite caps of the more northern areas. Only a little interstitial gypsum is present. Wedges of the limestone, separated by beds of more normal calcite-banded gypsum, make up the lower 300–400 feet of the formation. The so-called "petroliferous Castile" of the Loneman Mountain area is a tongue of banded calcite extending northeast from this area of Castile limestones. Apparently the bituminous material, the source of the strong petroliferous odor, was deposited with the calcite and was not derived from the underlying beds. A careful search of the limestones failed to show any microscopic fossils. Small quantities of chert are found along some of the bedding planes of the limestone, and in a few places concretionary masses several inches across had developed. Thin sections show a few dust-size quartz grains along some of the partings.

The bedded Castile limestones of the southern Delaware Mountains are relatively soft and should erode almost as fast as the enclosing gypsums. Most of them were removed before the deposition of the Rustler. The present outcrops are

about 10 miles from the original southwest edge of the Delaware basin. If the liming-up of the section was as rapid in the eroded part of the formation as it is in the present outcrops, the Castile may have been an almost solid limestone along the west margin of the basin. Unfortunately the few wells in the extreme south part of the Delaware basin do not show whether the Castile also limed up in that area. Certainly the basal beds in the intermediate San Martine area, of southeastern Culberson County, do not appear as limy as equivalent beds an equal distance from the Apache reef front farther west.

In addition to the primary variations in the calcite-banded anhydrite of the Castile formation, there are many secondary irregularities. Calcite laminae disappear in nodular masses of anhydrite. Concretionary anhydrite lenses grow between the partings and disrupt them. Bands of crinkled laminae appear to writhe about between flat beds, and in some transverse zones all evidence of bedding is lost. More important still is the faulting, fracturing, and slipping that characterize most of the cores and outcrops. Since most of the variations occur both at the surface and at depths of thousands of feet, it is assumed that most of them were produced by early diagenetic processes.

Interlaminated dolomite and anhydrite are present in several places in the evaporites of the southern Permian basin, but calcite-anhydrite banding of the type here described has not been noted anywhere in the Permian section outside of the Delaware basin.

In these descriptions, outcrop observations supplement information from cuttings, cores, and well sections, but one striking modification of the normal calcite-gypsum banding has been observed only on the outcrop. In the central and southern Delaware Mountains there are irregular areas where the gypsum is completely replaced by limestone and banded calcite. In extent these limestone masses, which resemble gash vein fillings, range in area from a few square feet to many acres. Most of them appear to lie in the lower and middle thirds of the Castile formation. Maximum thickness of the larger masses probably exceeds 100 feet. The limestone concentrations, being more resistant than the enclosing banded gypsums, stand up as hills in the eroded areas. The hills vary from low mounds, through haystack buttes to castellate peaks. Although the Castile formation was named for Castile Springs rather than for the well exposed rock towers, a more appropriate name than "castiles" can hardly be imagined for the limestone hills themselves.

In the northern castiles the dominant lithologic character is a concentration of brown calcite bands. In the better exposed outcrops it looks as though the gypsum originally interbedded with the calcite had been removed by solution and the openings thus formed partly filled by secondary carbonates, apparently aragonite, and some secondary gypsum. Unsupported masses of the rock broke off to form a breccia that is now firmly held together by secondary botryoidal growths of aragonite. The northern limit of the prominent castiles is a few miles south of the Texas-New Mexico line.

In the southern Delaware Mountains the castiles, like the limestones of the

Castile formation, contain a much smaller proportion of banded calcite, its place being taken by coarsely granular gray limestone. On weathered surfaces this rock is casehardened, but under the thin hard coating it is soft, almost friable, and crumbles readily under taps of the hammer. Brecciated angular fragments of banded calcite are enclosed in the granular groundmass that replaces the botryoidal cement of the northern castiles. The banding in many of these brecciated fragments shows that the calcite was never interbedded with gypsum. In the Paint Horse Draw area the brown banded calcite in the castiles is reduced to a minimum and the granular limestone weathers with the rounded surfaces of a soft sandstone. As a result the castiles are more bulbous and less steep walled than those farther north. Lack of bedding differentiates the limestone of the castiles from the normal limestones of the surrounding areas. Chert is very uncommon and a careful search failed to reveal any fossils. These southern castiles should not be confused with somewhat similar limestone hills in the upper part of the Delaware Mountain sand. The latter contain conspicuous amounts of chert as well as laminae and lenses of sand. They are also fairly fossiliferous.

No castile masses have been recognized in the subsurface. However, many of those noted are only partly exhumed and their extent is probably much greater than is apparent in the limited outcrop. The structures are clearly of secondary origin and they would not be expected far below the surface.

The salt beds, which are the principal markers in the Castile formation, are composed of practically pure sodium chloride. Impurities include blebs and crystals of anhydrite, and laminated calcite. No potash is present. The salt lenses can be divided into three groups. The lower and middle groups each have two members. The upper group is less regular and contains many stringers too thin to be shown on the sections. With the exception of the thin salt lens near the base of the Apache reef, as shown in the Deep Rock's Kloh No. 1, all the Castile salt is limited to the northeast part of the Delaware basin. The lower salt group is best developed in the north part of the salt-bearing area, the middle group in the north and central parts, and the upper group in the central and south parts. The southern limit of the lowest Castile salt is just south of the town of Pecos but the upper beds do not reach as far north as the New Mexico line.

In the Wheat pool of Loving County, Texas, where the base of the lower salt is used as a marker to predict the top of the Delaware Mountain sand, the interval from the base of the salt to the top of the Lamar shale varies from 183 to 185 feet.[13] Northward and northeastward the interval increases to about 400 feet. Southward it decreases to about 150 feet, but in any one locality the interval is sufficiently constant to be used in local areas for structural predictions.

Chert deposits in the Castile formation appear to be limited to the banded limestones and to the calcareous parts of the castiles in the southwestern Delaware Mountains. Even here the chert is a very minor constituent of the rock. A careful hand-lens examination showed no organic structures.

[13] John Emery Adams, *op. cit.*, p. 755 (1936).

Clastics noted in the Castile formation include fine quartz grains scattered through the calcite laminae. Their presence was unnoted until the rock was sectioned and examined petrographically. The size of these particles suggests that they represent atmospheric dust. Cores from one well showed structures resembling anhydrite pebbles in the bottom foot or so of the formation. They were not noted elsewhere and may be accretions rather than products of mechanical transportation. Udden[14] mentions the presence of shale, but deposits, if present, are limited.

Along the north and east borders of the Delaware basin the Castile is separated from the overlying Salado by an angular unconformity. Elsewhere the angularity decreases, but in the southern areas the two formations are separated by an even greater time break. In the western areas, where the Rustler beds rest on the truncated surfaces of the Castile, the angularity is apparently due to pre-Rustler uplift and erosion as well as to irregular hydration ahd solution of the Castile evaporites.

SALADO FORMATION

Above the Castile is another thick section of evaporites belonging to the Salado formation. The two formations are separated by an unconformity, accompanied by marked changes in distribution and lithologic character. But in spite of these great differences, there have been, and still are, difficulties in drawing the dividing line between them.

The Salado in the Delaware basin was truncated and completely overlapped by beds of the succeeding Rustler formation. Along many of the divides, tongues of Rustler still lap over onto the beveled edges of the Castile. The only Salado outcrops are thus discontinuous, poorly exposed patches of unbanded gypsum along the main drainage lines west of the Rustler Hills. In the subsurface the Salado, unlike the Castile, crosses the Capitan reef and is present in a large part of the southern Permian basin.

In the Salado formation, salt is more abundant than anhydrite. Many of the salt beds, especially the upper ones, in and around the north end of the Delaware basin, contain potash and other bittern minerals. Polyhalite is the most widespread of the potash-bearing minerals. The base of the polyhalite deposits transgresses upward across the salt section toward the southwest. None is found in the salts south and west of the Pecos River. Many of the potash-free salts of the formation are also red, due to the presence of red clastics and iron oxides. The lithology and stratigraphy of the salt and associated beds in the northeast part of the Delaware basin have been worked out and described by geologists and others studying the commercial potash deposits of the area.[15] In addition to the potash,

[14] J. A. Udden, *op. cit.*

[15] W. T. Schaller and E. P. Henderson, "Mineralogy of Drill Cores from the Potash Fields of New Mexico and Texas," *U. S. Geol. Survey Bull. 833* (1932).

G. R. Mansfield and W. B. Lang, "Texas-New Mexico Potash Deposits," *Univ. Texas Bull. 3401* (1934), pp. 641–832.

clastics, and common red coloration, the Salado salts contain blebby anhydrite inclusions and mats of coarse, interlocking anhydrite crystals as well as the fine granular masses of anhydrite which characterize the salts of the Castile. Salado salts in the south-central part of the Delaware basin are much cleaner than those in the areas near the north rim.

Dolomite and magnesite are the common Salado carbonates, although calcite-banded anhydrite is present in the lower beds of southeastern Reeves and western Pecos counties. The dolomite and magnesite are present as stringers or as diffused grains in most of the anhydrite members at the north end of the Delaware basin. Near the Texas line the carbonates, especially in the upper part of the section, are concentrated into beds. Outside of the salt areas dolomite becomes more prominent and some of the beds can be correlated from well to well. The more general lack of correlation may be due to the wide spacing of control wells in the southern and western areas, but is more probably due to discontinuity of beds. In the south end of the Delaware basin the proportion of dolomite increases, and in the Humble's Kokernot No. 1, the southernmost well in the basin, bedded dolomites make up approximately 20 per cent of the Salado section. This concentration supports the correlation of the Salado with the Tessy formation of the Glass Mountains. Dolomite is also prominent in the western part of the basin, but no Salado dolomites have been recognized on the outcrop. Presumably, if found, they could be differentiated from Rustler dolomites by the absence of a basal conglomerate.

Sands and silts are encountered in many parts of the Salado section. The sands are coarser than most of the Permian sands but they are not characterized by the frosted quartz grains so common in the Yates and Dewey Lake formations. Both red and gray sands are present. A tongue of bedded sandstones extends south from the vicinity of Carlsbad almost to the Pecos County line. The source of supply seems to have been at the north and west. The sands are most extensive near the top of the Salado formation. The location of this sand barrier probably had some bearing on the thick accumulations of potash salts that occur in equivalent beds northeast of the main sand area. Most of the salt has been dissolved out of the Salado section in the sandstone areas, leaving a broad irregular solution trough. The position of this trough is clearly shown on the cross sections. The close association of this solution trough with the distribution of the sandstones suggests that the porous sand served as a conduit for the circulating salt waters. Isolated patches of salt were left west of the trough in northern Reeves and Culberson counties.

One sandstone member in the upper Salado of the northeastern Delaware basin and adjacent platform areas stands out conspicuously as a stratigraphic

---

George A. Kroenlein, "Salt, Potash, and Anhydrite in Castile Formation of Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23 (1939), pp. 1682–93.

Walter B. Lang, "Basal Beds of Salado Formation in Fletcher Core Test, near Carlsbad, New Mexico," *ibid.*, Vol. 26 (1942), pp. 63–79.

marker in wide areas. This thin sand, rarely more than 10 feet thick, lies just below Anhydrite No. 12 of the Kroenlein section. It is fine-grained sand and has the typical orange-red color of the Upper Permian sands. On the assumption that such a widespread, thin sandstone sheet must have spread over an almost level surface, the north end of the accompanying longitudinal section was aligned upon this member where it is present. A member so important in working out the sedimentary and structural history of this thick section of sediments is deserving of stratigraphic recognition. The name Vaca Triste, from Vaca Triste Draw, is proposed for this member of the Salado. The type section of the Vaca Triste sand member of the Salado is in the Continental's King well No. 1, Sec. 26, T. 25 S., R. 32 E., Lea County, New Mexico. In this well, which is shown on the north-south cross section (Fig. 2), the sand was encountered between 1,555 and 1,565 feet. The sample log for this part of the section is as follows.

Depth in Feet	
1,500–1,520	Anhydrite .8, salt .2 (Anhydrite No. 12)
1,520–1,530	Anhydrite .2, salt .8
1,530–1,555	Salt
1,555–1,565	Fine red sand (Vaca Triste member)
1,565–1,580	Anhydrite

Cuttings from this well are kept in the Standard Oil Company of Texas collection in Midland, Texas, and in many other collections in the area. The Vaca Triste sand in this well contains a showing of water.

Silts and shales are less conspicuous but more generally distributed than sands in the Salado section. Colors include brown, green, blue, gray, red, pink, violet, and black. These finer clastics are commonly lost in cuttings from oil wells but are very conspicuous in the potash core tests. One prominent member near the base of the Salado is named La Huerta silt.[16] Numerous other unnamed members, of equally wide distribution, can be recognized in the upper part of the section.

The anhydrites of the southern and western Salado areas are rather featureless deposits. The few cores examined show that the anhydrite is thin-bedded and blue-white in color. Outcrops of probable Salado age show some warping, but less evidences of thrusting and contortion of bedding than is observed in the underlying Castile. This is possibly due to the fact that there are no good outcrops and no contrasting beds easy to follow with the eye. In the main salt section of the northeastern Delaware basin, the anhydrites fall into two groups—discontinuous lenses, and widespread members which serve as markers. Most of the widespread members of the potash mine area were given numbers by Kroenlein.[17] A few changes in the correlation of these numbered beds are here adopted for the wells in southern New Mexico. No single anhydrite member can be carried over the entire salt-bearing area of the Delaware basin. The anhydrite marker members almost everywhere contain inclusions of salt, and thin stringers of silt and magnesite or

[16] W. B. Lang, *op. cit.* (1942).

[17] George A. Kroenlein, *op. cit.*

dolomite. Two of them are recognized by name. The Fletcher member marks the base of the Salado in the northern Capitan reef area. The widespread Cowden anhydrite occurs 150 to 200 feet higher in the section.

Dark brown, calcite-banded anhydrite is present in southern Reeves and western Pecos counties, where the top of the banded section is about 500 feet above the base of the Salado. The banding is darker than is common in the banded Castile and the rock gives off a strong sulphur-dioxide odor when digested in acid. The calcite-banded anhydrite members of the Salado are thin and are separated by thick beds of salt. They are apparently limited to an area near the nadir of the Delaware basin.

No chert was noted in any of the Salado samples, but a few small euhedral quartz crystals with short prisms and bipyramids are scattered through the salt. Here and there grains of pyrite are found in the dolomite.

At its inception the Salado lagoon was apparently limited to a narrow crescentic trough just inside the north and east rim of the Delaware basin. The first evaporites deposited in this part of the lagoon seem to have been anhydrites. No distinctive characteristics were recognized that would separate Salado anhydrites from those of the underlying Castile. For this reason only the general position of the contact is shown in the accompanying sections. The early anhydrite deposits were followed by salt. Subsidence of the platform at the north and east quickly permitted the salt-depositing waters to cross the platform rim and cover large areas of the southern Permian basin. The earliest beds of the original trough are probably older than the Fletcher anhydrite on the crest of the Capitan reef, but they are included with the Salado because they lie above the unconformity which separates that formation from the underlying Castile.

While the Salado sea was sweeping widely north and east, it was slowly creeping southward up the center of the Delaware basin. By the time the sea floor had subsided sufficiently for approximately 600 feet of salt and anhydrite to be deposited in the northern and eastern marginal troughs, the whole Delaware basin was submerged. The resulting disconformable distribution is clearly shown on the stratigraphic sections. The south edge of the original trough may have been localized by solution of the underlying Castile salt, but the formation of the trough itself was due to crustal movements in the Castile-Salado interval. The distribution of the early Salado beds indicates that they were deposited in an arm of the sea advancing across the Permian basin from the west or southwest. All evidences of the extent of this marine arm were removed or covered by post-Permian erosion and deposition. A southwest sea connection seems probable because the Ochoa sea never extended much farther west than the present limits of the Delaware basin. In later Salado time the entrance apparently shifted to the south end of the basin.

Even though the southern Delaware basin was not submerged until a considerable thickness of salt had been deposited in the northern areas and across the platform behind the Capitan reef, the negative central part of the basin quickly

regained dominance. As a result, the thickest Salado section, exceeding 2,200 feet, is present in east-central Loving County. Still farther south, in western Pecos County, the lower part of the Salado loses many of the conspicuous northern anhydrite members and becomes an almost solid section of salt. The anhydrite members that are present here contain banded calcite similar to that in the underlying Castile.

North and east of the Pecos River much of the Salado section above the Vaca Triste member consists largely of salt with three prominent anhydrite members. The upper salt beds extend northeastward across the reef rim of the Delaware basin and are recognized over most of the Central Basin platform. To the south and west, however, these beds are either missing or grade into anhydrite. The salt beds below the Vaca Triste also disappear toward the south and west. Limitation on the west is partly due to post-Salado erosion and solution and partly to nondeposition. The most rapid subsidence took place in the east-central Delaware basin and it is here, as already mentioned, that the thickest and most nearly complete Salado section was laid down.

Salado salt beds west of the Pecos River, in northern Reeves County, are separated from those on the east by a solution trough. The site of the solution trough was an area of thick sand deposition. As the sand rises in the section toward the southeast, so does the bottom of the solution trough. Lenses of sand interbedded with salt, in some of the wells along the margins of the slump, prove that the sand concentrations in the Salado section underlying the trough are residual and were not washed in after the sag developed. The Vaca Triste is apparently an attenuated sand stringer extending out from this sand body.

The Salado unconformably overlies the Castile evaporites of the Delaware basin and the uppermost Guadalupian sediments of the surrounding areas. There is no evidence of extensive pre-Salado erosion. This may mean that the basin was an area of very slight rainfall. It seems probable, however, that the uppermost Castile salts were dissolved to form a shallow solution valley along the original margin of these salts. This and the tilting of the Delaware basin northward probably mark a time break between the two formations. The unconformity between the Salado and the overlying Rustler formation is marked by extensive erosion and solution.

It is probable that the Salado should be correlated with the Tessey formation of the Glass Mountains. The Tessey is made up of practically pure, almost nonfossiliferous dolomites and probably represents the back-reef facies of a post-Capitan reef, into which the limed-up section of the southern Salado appears to grade.[18]

RUSTLER FORMATION

Deposition of the Rustler, the third formation of the Ochoa series, was preceded by a period of uplift and erosion in the area along the west edge of the Dela-

[18] P. B. King, "Geology of the Marathon Basin, Texas," *U. S. Geol. Survey Prof. Paper 189* (1937), p. 106.

ware basin. This erosion stripped off all the western Salado and may have truncated the entire Castile formation as well. The lowest Rustler outcrops observed are about 100 feet above the top of the Delaware Mountain group. As a result of uplifts beyond the limits of the Delaware basin, the oldest deposit of the Rustler formation, in its western outcrops, is a clastic member. Included are coarse, siliceous conglomerates with well rounded pebbles up to 2 or 3 inches in diameter, coarse gray sandstones, traces of red and yellow shale, coarse dolomite conglomerates, and bedded gray and buff dolomite. Many of the siliceous pebbles are etched in a peculiar manner with all the broken crystals of the original surface spalled out, leaving well rounded pebbles covered with unmarred crystal faces. The bedding in all these deposits seems to be distorted. Toward the east the conglomerates grade into sandstones.

Where the basal sandstones of the Rustler rest on the beveled surfaces of the Salado, as in the area south and east of Carlsbad, they are characterized by abrupt irregularities in thickness.[19] Apparently these variations are due to the filling of salt solution valleys in the surface of the Salado. Above the basal clastic phase, the Rustler is largely an evaporite formation and marks the final stage of evaporite deposition in the southern Permian basin.

In the subsurface where the complete Rustler section is preserved, it can be divided into two main parts, an upper 150- to 175-foot bed of anhydrite or gypsum; and a lower group of dolomite, anhydrite, sand, and shale members. Along the southwest limits of the Rustler area the anhydrites of the lower group grade into dolomites and the dolomites into limestones. Toward the north and east the the dolomite stringers, in turn, decrease in prominence, and at the northeast edge of the Delaware basin part of the upper anhydrite and the anhydrites of the lower group grade into salt. Thus in crossing the Delaware basin from southwest to northeast, we find, within the limits of one formation, an almost complete sequence of evaporite deposits.

Where the Rustler carbonates crop out in the Rustler Hills of eastern Culberson County, the section consists of dense, brecciated limestones and dolomites with rough, pitted, weathered surfaces, interbedded with sandstones and limestone conglomerates. Much of the pitting is due to the solution of gypsum inclusions. Many of the gray and green shales of the subsurface take on a purple cast after weathering on the surface. The maximum thickness here is about 375 feet and none of the upper anhydrite is exposed. Richardson collected a few fossils from these outcrops.[20] These pelecypods apparently lived under very unfavorable conditions, have not been found elsewhere, and are not diagnostic of age. Small amounts of sulphur have been produced from fault zones in the Rustler Springs area and some copper stains were noted. The most detailed published description of this area is that by Porch.[21]

[19] W. B. Lang, personal communication.

[20] G. B. Richardson, "Report of a Reconnaissance Survey in Trans-Pecos Texas North of the Texas and Pacific Railway," *Univ. Texas Min. Survey Bull. 9* (1904), p. 40.

[21] E. L. Porch, Jr., "The Rustler Springs Sulphur Deposits," *Univ. Texas Bull. 1722* (1917).

Unlike the Salado, the Rustler formation crops out over widely scattered areas both east and west of the Pecos River. Outcrop distribution is controlled by erosion, solution subsidence, and burial under Triassic and Quaternary cover. The western outcrops are limited to the basal carbonate and clastic section, with the upper anhydrites suggested by a gypsite plain east of the Rustler Hills. As the only resistant member in a thick series of softer beds, the limestones form low scarps and floor many of the gentler slopes. The slumping and disruption of the hard members due to creep of the underlying gypsum was described by Shumard,[22] who crossed the region in 1855.

East of the Pecos River, in central Eddy County, New Mexico, is a small area in which the upper as well as the lower part of the Rustler is exposed. Here, where the upper Rustler stratigraphy is similar to that of the north-central part of the Delaware basin, Lang measured the following section.[23]

1. 30 feet gypsum
2. 30 feet gypsiferous dolomite
3. 100 feet gypsum
4. 30 feet redbeds
5. 20 feet gypsum
6. 35 feet dolomite
7. 30 feet redbeds
8. 70 feet gray sandstone
9. 35 feet redbeds
10. 130 feet gypsum
11. 5 feet redbeds

The first five members in the foregoing section belong to the upper Rustler, the others to the lower part of the formation. The 30-foot gypsiferous dolomite, No. 2 in the sequence, is a persistent marker in the north half of the Delaware basin. For this stringer Lang favors the name Magenta member of the Rustler formation, after Magenta Point north of the Laguna Grande salt lake, and this name is used on the stratigraphic sections. For the 35-foot dolomite, No. 6 in the section, he favors the name Culebra member of the Rustler formation, from Culebra Bluff on the east side of the Pecos River where the member is well exposed. Because this member is a good marker in the subsurface, the name Culebra is also used in the cross sections.

The lower part of the aforementioned section is characteristic of the extreme northwest part of the Delaware basin and is limited to the area of pre-Rustler solution troughs. Perhaps the exceptional thickness of sandstone in the Rustler of this area is due to a recurrence of the processes that supplied the thick Salado sands in the same area. In the subsurface, farther south and east, another prominent dolomite bed appears near the base of the gray sandstone, No. 8 of the Lang section. This is the lower of the two main Rustler dolomite members.

Local features include a zone of euhedral quartz crystals in the anhydrite between the Magenta and Culebra dolomites, and oölites in one or the other of the two main dolomite members. The oölites are most common in that part of the Rustler overlying the Capitan reef and the back-reef areas.

[22] Geo. G. Shumard, "Observations on the Geological Formations of the Country between the Rio Pecos and the Rio Grande, in New Mexico near the Line of the 32nd Parallel," *Trans. St. Louis Acad. Sci.*, Vol. 1, No. 2 (1858), pp. 5–7.

[23] W. B. Lang, "Geology of the Pecos River between Laguna Grande de La Sal and Pierce Canyon," *New Mexico State Engineer 12th and 13th Bien. Rept.* (1938), p. 84.

The contact of the Rustler and overlying Dewey Lake formations appears to be conformable. In the central part of the Permian basin the same can be said of the Rustler and Salado, but along the west and north margins of the Delaware basin the Rustler unconformably truncates the entire Salado section. The sharpest angular unconformity is in the western Delaware basin where the Rustler rests on the basal members of the Castile formation and is reported to rest on the Capitan limestones of the Apache Mountains. Uplift and erosion in this area may have been as much as 2,000 feet.

The Rustler marks the final incursion of the Permian sea into West Texas. In general, this sea was much fresher than those of the Salado and Castile, but being extremely shallow, gradations from one type of evaporite to another were more abrupt. If any of the Rustler is exposed in the Glass Mountains it is included in the Tessey formation of that area. The southernmost subsurface section can be differentiated from the outcropping Tessey only by the presence of small quantities of anhydrite. Even though the Rustler is separated from the underlying Permian by the most pronounced unconformity within the Permian system in West Texas and New Mexico, there is no reason for assuming that it is post-Permian in age. The basin of sedimentation is the same; the seaway supplying the water is the same; the processes of sedimentation are the same; and the character of the sediments themselves is the same, even down to the red polyhalite in the salt and the frosted quartz grains in the sands, as those of the older Permian beds.

DEWEY LAKE FORMATION

The Dewey Lake is a redbed formation in sharp contrast to the evaporites of the lower Ochoa. The gypsum that is present with the orange polished sands and red shales occurs as cement, secondary crystals, and veins. The coarse frosted quartz grains, so characteristic of the basal Dewey Lake beds in areas on the east, are missing in the Delaware basin section. The greatest thickness of Dewey Lake beds is just under 350 feet. In this area the formation is limited to the structurally low areas along the east and south edges of the Delaware basin, and no outcrops are known. Apparently pre-Triassic erosion stripped the unconsolidated redbeds from the surface of all the higher exposed areas, leaving a Rustler pavement. Then the area was completely covered by Triassic and Cretaceous sediments that still lap far beyond the limits of the truncated Dewey Lake formation.

Basal Triassic redbeds are differentiated from those of the Dewey Lake by their deeper red color, which here and there borders on purple, by their greater content of gypsum, their flood of dark minerals, their seeming lack of compactness, and their wider variations in grain size. The so-called frosted grains of the Triassic are much more polished than those of the Permian, and they commonly include a much higher percentage of reddish quartz grains. It seems probable that whereas the Permian frosted grains are frosted by solution, those of the Triassic are frosted by wind action. Some of the difficulty in separating the Permian and Triassic redbeds is due to the fact that the Triassic contains a large percentage of

reworked Permian. White spots are common to most redbeds and are not diagnostic of age. Such spots are caused by reduction of the iron around an enclosed fragment of organic material or some similar reducing agent.

ORIGIN OF EVAPORITES

The origin and distribution of the various evaporites in the Ochoa series were due to physiochemical processes, many of which are not fully understood. It is the plan here to see whether adequate explanations of the several phenomena can be developed within the limits of the critical geological data.

Baker[24] has presented very convincing geological arguments to show why the extensive salines of the Permian basin must have had a primary marine source. This hypothesis is accepted without question. Observed data suggest that the evaporites were deposited in an Ochsensius-type barred basin of epi-continental extent. Water losses from such a basin would be by evaporation and by outflow of waters piled up by floods, high tides, and storms. If these losses exceeded precipitation plus inflow of streams and springs, sea water would be drawn in over the bar to make up the deficiency. Continuation of this excess loss and its replacement by sea water would lead to precipitation of evaporites. Variations in the composition and distribution of these evaporite deposits would depend on the size, shape, and depth of the basin, the distribution and extent of the fresh-water supplies, and the ease and regularity with which inflowing sea water could cross the bar.

Evaporation of sea water in a restricted container, such as a beaker, produces a regular sequence of precipitates mixed with or superposed one upon another. In larger, natural, barred basins, tens or hundreds of miles across, with a single continuous marine connection, equal evaporation per unit of area would cause an inward slope across the evaporating pan and a consequent continuous migration of the brine from the entrance to the innermost end of the basin. Increasing concentration during this journey would cause successive precipitation of the least soluble constituents in a lateral rather than a vertical sequence. The normal order of the geologically important evaporite sediments is limestone, dolomite, anhydrite, salt, and rare bitterns. Intermittent marine connections in a sizeable basin should produce deposits similar in distribution to those of the laboratory experiments. During closed periods evaporation would lower the surface of the water in the barred basin below that of the adjacent sea. Upon the breaking-down of the barrier great quantities of sea water would rush in to fill the basin up to sea-level. This water would spread over the whole area and only after it became practically stationary would evaporation produce any appreciable decrease in volume or increase in concentration.

The Castile formation seems to fulfill the requirements for intermittent marine connections while almost all the other Permian evaporites appear to have been deposited in barred basins with nearly continuous marine connections. The

[24] C. L. Baker, "Depositional History of the Redbeds and Saline Residues of the Texas Permian," *Univ. Texas Bull. 2901* (1929), pp. 9–65.

Castile is fairly consistent lithologically from bottom to top and from one end of the basin to the other. It seems that the minor differences can be most readily explained if we assume, in addition to the intermittent marine connections, that the beds were deposited in waters of greater than normal depth and in a relatively restricted basin.

All the geological evidence indicates that the marine waters that entered the Castile sea entered from the south or southwest through one or more narrow channels. A sand-dune ridge, perhaps made up of calcareous sands and protected by organic reefs, would be a logical type of barrier to shut off migration through such channels. Breaches could be produced by storm waves and sealed off by normal wind action. Alternate breaching and sealing of a barrier of this type might well be a seasonal occurrence. Recurrent closing and opening of the barrier would allow the waters in the basin to be lowered by evaporation or to be raised by freshening floods. Initially the waters of the Castile sea were fairly uniform in composition, and because they were derived from the open sea, salt concentrations would be those normal to the waters of the Permian oceans, which probably closely approached those of the present sea. Waters drawn across the bar would be of the same character and would carry a normal planktonic fauna. As soon as a solid barrier shut off the marine inflow, evaporation would start decreasing the volume of the relict waters and this would cause precipitation of the salts in the reverse order of their solubilities. Increased concentration would eventually cause the death of most of the organisms in the barred-basin waters.

The present average rate of surface evaporation in the area of the Delaware basin ranges between 6 and 9 feet a year. At this rate the original 1,700-foot basin would have been emptied in 200–300 years if no additional water was added. Probably long before complete desiccation occurred the barrier was broken down and a fresh supply of sea water entered. The entering water would be lighter than the concentrated water already in the basin. Because of this difference in density there would be little if any vertical mixing or diffusion between the zones of different concentration. Since only the surface suffers evaporation, this top layer of unconcentrated water would be acted on as a unit. Concentration would cause the precipitation of the least soluble constituents. Of these, calcium carbonate is the only one abundant enough to furnish a geologically appreciable deposit. If only 6 to 9 feet of water had entered the basin, the resulting layer of limestone would be paper thin. Before the thin top layer of unconcentrated water had been completely evaporated, the increase in gravity would allow the residue to sink into the underlying gravity stratum. By the time this point was reached the floating organisms would have been killed by the increasing concentration, and their remains would have showered down with the $CaCO_3$. Numerous repetitions of this partial evaporation would eventually lead to the establishment of an even more pronounced gravity stratification. In the final stages the bottom brines would have lost practically all of their original salts less soluble than sodium chloride while at intermediate depths the brines would be saturated with calcium sul-

phate. Once the calcium carbonate precipitate had settled through the top water, there would be no tendency for re-solution, because the bottom waters were already concentrated and the decrease in pressure from shallowing of the water would decrease its ability to hold CO_2 in solution.

The second geologically important precipitate is normally dolomite, but there is no dolomite present in the Castile evaporite section. The reason seems to be connected with the depth of the water and the concentration of CO_2. Most of the Permian evaporites outside the Delaware basin were deposited from waters only a few inches or at most a few feet in depth. Temperature and pressure and chemical composition varied but little from top to bottom and most of the carbonate was deposited from relatively concentrated waters. At the beginning of Castile deposition the Delaware basin was almost 2,000 feet deep and at the close may have held waters more than 100 feet deep. Most of the carbonate was precipitated from surface waters of relatively low concentration. Calcium carbonate deposited from waters low in sulphates goes down as calcite, and from high-sulphate waters as aragonite. Calcite is a stable mineral and once formed is not easily altered. Aragonite is unstable and in recrystallizing in the presence of a concentrated magnesium solution might be expected to form dolomite. Another hypothesis that may be advanced is that increasing pressure with depth allows sea water to hold higher concentrations of carbon dioxide in solution. It requires much less of an excess of CO_2 to hold $MgCO_3$, which is just another way of saying that magnesium carbonate is more soluble than calcium carbonate. The presence of organic matter such as that staining the calcite laminae of the Castile does not seem to be important because similar organic deposits are present in many of the Permian dolomites.

The second geologically important precipitate to be deposited in the Castile sequence was calcium sulphate. It makes very little difference now whether the $CaSO_4$ was deposited as primary gypsum or as anhydrite, or even a mixture of the two. Probably gypsum predominated and the shearing and crumpling so conspicuous in cores and outcrops was developed during dehydration as a result of burial, or by pre-solidification flowage. Once started, precipitation of $CaSO_4$ would continue until it was all out of solution or until the evaporating surface was insulated by a cover of fresh surface waters. The quantity of gypsum precipitated could greatly exceed that of the calcite because the amount in solution per unit of water was greater and the layer of water to be evaporated between the beginning and close of $CaSO_4$ deposition was much thicker. The gypsum, like the calcite, would not be redissolved when once precipitated because the bottom brines were too highly concentrated to hold additional calcium sulphate.

The third geologically important precipitate to form with continued evaporation was sodium chloride salt. Its presence in the column would indicate almost 90 per cent desiccation. The small quantity of brine remaining at this stage would be concentrated in the deepest parts of the depression, and it is here that the deposits of salt would be laid down.

Reëstablishment of inflow would find the level of the water in the basin lower than sea-level. Fresh waters would rush in to fill the void, but because of the differences in gravity there would be little mixing, and the fresher waters would spread rapidly to form a light surface blanket over the entire basin. The thickness would depend, of course, on the brine level. Except in cases of practically complete desiccation, there would be no resolution even of the most soluble precipitates because they would be insulated by a layer of heavy, concentrated brine. With the freshening of the water the processes of evaporation would begin another cycle.

The calcium carbonate precipitated from the surface waters would be mixed with considerable organic material. On consolidation this would produce the brown calcite laminae so typical of the Castile. During the colder season of the year evaporation would be very slow compared with summer losses, and the coolness of the atmosphere would tend to cool the water and increase its power to hold CO_2 in solution. It is, therefore, probable that the calcite laminae each represent the deposits of a summer or portion thereof.

Further evaporation and concentration would cause the precipitation of gypsum. Upon consolidation under pressure the gypsum would be dehydrated to anhydrite. Ordinarily by the time a fraction of an inch of gypsum had been precipitated, there would be a new incursion of the sea and the process would be repeated. This would explain the regular alternation of calcite and anhydrite laminae. An extensive, uninterrupted period of evaporation would result in the formation of a thick anhydrite. The next incursion of the sea would find the surface of the brine a greater distance than normal below sea-level, and the filling of the basin would result in a much thicker layer of new water, most of which must be evaporated before a renewal of gypsum precipitation could take place. Evaporation of the exposed surface waters in the area of the Delaware basin varies from 70 to 110 inches a year at present. It was probably of somewhat the same magnitude in the Permian. A hundred inches of water from the present sea would produce a thin layer of limestone. Two thin laminae without intervening anhydrite, such as are common in the calcite caps over the thick anhydrites, previously mentioned, would thus represent 200 inches or about 18 feet of evaporation. Two hundred thin laminae would require about 1,800 feet of water. Because this figure approaches the original depth of the basin, it is probable that the thicker calcite caps were possible only when renewed incursions delayed the renewal of gypsum precipitation far beyond its normal period. Although the calcite laminae are probably summer deposits, the anhydrites, especially the thicker ones, may have taken years to form, so that the counting of laminae is not a particularly accurate method of measuring the length of the Castile age. The method is further complicated by the introduction of several salt lenses in the section.

Apparently several times during Castile deposition evaporation proceeded so far before refreshing that salt was precipitated, but the amount of salt in the Castile is much smaller than the amount that should be present if normal Permian

sea water were evaporated to the stage of salt deposition in a barred basin. There is less salt than anhydrite in the Castile and perhaps even less than there is banded calcite. It is improbable that the Permian ocean was abnormally free from NaCl during Castile time. The ocean should have had much the same concentration as during the preceding Whitehorse and following Salado stages when salt predominated. If the Castile were a thin formation the salt might have remained in solution until deposition ceased and then have escaped to the sea, but it would be impossible for the salt equivalents of 1,800 feet of anhydrite to have remained in solution in a shallowing basin. Therefore, it must be assumed that much of the concentrated brine escaped.

We do not know what or where the barrier was that separated the Castile from the open ocean. If, as has been suggested, the calcite anhydrite banding and the associated development of over-thickened anhydrite with calcite caps were produced by breaching and sealing, an effective barrier must at times have been present to prevent inflow of new sea water. If the breaching were deep enough, the concentrated bottom brines could and would have escaped. Deep breaching, of course, would have required a large amount of refilling before sealing was possible. If the barrier was an organic reef, deep cutting would have been difficult and the rebuilding would probably have required many years. This would have interfered with the regular depositional sequence and no such stratigraphic breaks have been recognized. Another and perhaps more plausible explanation might be that the heavy concentrated brines escaped through a slightly permeable barrier. With limited permeability outflow would occur when the gravity and pressure of the brine in the barred basin was higher than that of the water at the same level outside. Salt-depositing brines have gravities as high as 1.25 or higher against 1.025–1.03 for sea water. A slow outward seeping of heavy brines into the deep Marfa basin and their subsequent escape to the ocean would explain the limited amount of salt in the thick Castile evaporites.

Distribution of the salt lenses indicates that the deepest part of the basin in early Castile time was at the northern or inner end. Later it moved successively southward so that the upper salt lenses occur in the east-central basin area. In addition to being tilted, the basin shallowed so that the later salts are more numerous but thinner and less regular than the earlier ones. The chances of a shallow basin being completely desiccated without being freshened are much greater than those of a deeper one, but the amount of precipitate to be furnished by such a complete drying-up is lessened.

Under ideal conditions the calcite and gypsum laminae might be deposited with uniform thicknesses over the entire basin floor. Actually there seems to be more calcite in the south and west parts and it is completely missing from the higher Castile beds in the northeastern areas. Perhaps the inrushing fresh waters, lighter though they were, crowded the heavy brine downward, outward, and upward ahead of them so that the fresher waters never reached or were very thin at the inner end of the basin. Or it may be that evaporation removed most of the

calcium carbonate during the journey of the water from the entrance to the northeast edge of the basin, or a combination of these and other factors may have been responsible. The fact that the brown organic laminae extend beyond the edges of calcite precipitation supports the hypothesis that the calcite was lost while the water was moving but not yet concentrated enough to kill all the floating organisms. At present we can not recognize great concentration of calcite in the Castile that might localize the entrance to the basin, unless it be the apparent thickening of the limestones in the Seven Heart Gap area of the southern Delaware Mountains. This would imply a break in the Capitan reef in the southern Salt Flat area.

The shallowness of the water in most of the post-Capitan seas largely determined the character and distribution of the Salado and Rustler evaporites. This shallow depth, coupled with the great expanse of evaporating area and an almost continuous connection with the sea, assured a steady and relatively rapid flow of water from the mouth to the innermost end of the basin. Because of this movement, during progressive concentration and precipitation, there was little tendency, as in the Castile, for the geologically important evaporites to alternate vertically or to show much lateral mixing. However, contacts between areas of the various types of deposits were not stable, but shifted back and forth as the supply of sea water or the area of the basin varied.

Because of its depth the Castile basin seldom if ever completely dried up. The Salado and Rustler seas, on the other hand, were mostly so shallow that sealing the barrier for a couple of years would have caused disappearance of all except the hygroscopic water. After one of these periods of exposure, inflowing waters would find soluble salts exposed in large areas of the basin. Because of the speed of inflow during the recursion, the waters reaching these areas would be unsaturated and fresh enough to dissolve considerable quantities of the exposed salts. The Upper Permian evaporites all contain minute quantities of fine clastic material such as silt and clay. These fine clastics were probably distributed by the wind. Periods of re-solution would concentrate these insoluble clastics in a thin layer of bottom mud. And since wind action had been going on constantly during the retreat of the sea, these mud beds would frequently be thick enough to form visible silt beds. Ralph King[25] suggests that such beds as the LaHuerta silt of Lang[26] and numerous other silt beds in the Salado salts mark periods of desiccation and resolution. It would not have been necessary for the whole basin to have been dried up but only for those parts in which soluble salts had been deposited. The thicker, coarser Salado sands in the northwestern part of the Delaware basin would also have been distributed by wind action. Advances of the windblown sands would take place during periods of quiescence. The sands would be reworked and buried during periods of active subsidence. As the rate of sinking slowed down, fresh extensions of the sand would occur. The same results would be secured if the sands were deposited by ephemeral desert streams.

[25] Ralph King, personal communication.

[26] Walter B. Lang, *op. cit.* (1942).

Calcite-banded anhydrites are present in the Salado section of the south-central Delaware basin. They occur in an over-thickened section of middle Salado evaporites and are associated with an exceptionally complete salt section. These two factors together suggest that locally the bottom was sinking more rapidly than normal and that the waters were fairly deep. Heavy salt brines would concentrate in these deeps while the depth, temperature, pressure, or other factors responsible for banded anhydrite would act on the less soluble evaporites.

Theoretically the anhydrite layers in the subsurface should be about two-thirds as thick as the corresponding gypsum layers at the surface. There is, however, no way of checking the hypothesis that hydration of anhydrite in the Ochoa has produced an appreciable increase in volume. There are no continuous exposures showing both massive gypsum and massive anhydrite. Examination of deep anhydrite cores and surface gypsum samples shows laminae of comparable thickness in both facies. General relations in this and other parts of the southern Permian basin suggest that hydration is not accompanied by any great change in volume when it occurs under a heavy cover, as most of it apparently has. Gypsum creep on slopes and the arching of surface beds seem to be due to recrystallization of a much later date. Meier and Griley[27] briefly discussed the problem of hydration in Oklahoma.

ORIGIN OF CASTILES

The distribution and structure of the castiles and their relation to the Castile outcrops suggest that the limestone masses are secondary features. Sink-holes are relatively common in the gypsum area. Probably most of them are located along fractures opened during hydration of the buried anhydrite. Masses of limestone, similar to those of the adjacent castiles, are present in the mouths of some of these sinks. Calcium sulphate is more soluble than calcium carbonate and while the gypsum laminae are being dissolved from the necks of the sink-holes the calcite laminae apparently serve as attachment points for secondary calcium carbonate drawn from surface waters flowing into the sinks. Austin F. Rogers, in a personal communication to Lon D. Cartwright, Jr., remarked that thin sections of the rock from one of these castiles clearly showed the carbonate replacing the gypsum. The brecciated appearance is due to fragments falling from the walls of open passages that were later filled with secondary limestone.

SALT SOLUTION

Solution is effective wherever soluble salts are exposed to the action of unsaturated waters. It is not surprising, therefore, to find that solution has extensively modified the sedimentation, distribution, and structure of the highly soluble Ochoa rocks in the Delaware basin.

The oldest evidence of extensive salt solution in the Ochoa section was noted at the break between Castile and Salado sediments. The stratigraphic sections

[27] J. Lawrence Meier, "Anhydrite Gypsum Problem of Blaine Formation, Oklahoma," *Bull. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1297–1312. Discussion by H. L. Griley, *ibid.*

show that the upper, or third, group of Castile salts forms a north-south ridge along the center of the salt basin. These salt beds terminate abruptly at the edge of a trough filled with an over-thickened section of Salado salts and anhydrite. The trough was formed when pre-Salado solution exposed and removed the thinly buried edges of the uppermost Castile salts.

Between the close of Salado and the beginning of Rustler deposition, the west edge of the Delaware basin was uplifted and truncated. This erosion left a series of parallel solution valleys, where the salt members had cropped out, separated by gypsum ridges. The irregular topography was covered and preserved by the Rustler sediments. Closely spaced core holes in the potash areas south and east of Carlsbad show these trenches. They are filled with irregular basal Rustler beds that are not present elsewhere in the basin. No great solution troughs were developed at this time, however, probably because of the thinness of the salt beds available for solution.

The next great period of solution began in the Triassic. Salado salts were removed along the east edge of the Delaware basin from the Pecos River northward into New Mexico. The solution trough developed at this time is 800 or 900 feet deep and is filled by an over-thickened section of Triassic. Early subsurface geologists, working with scattered wells and impressed by the differences in structural elevation between the Delaware Mountain sandstone and the top of the "Big lime" behind the Capitan reef, assumed that the displacement was due to a major fault downthrown on the west, and that the salt was cut out by this fault. Later field and subsurface work proved that the structural difference in the underlying Guadalupian beds was depositional and that the faulting in the Rustler was due to the removal of salt by solution. This slump faulting is diagrammatically shown on the west-east cross sections. It is probable that slight warping along the Capitan reef, at the close of the Paleozoic, fractured the overlying cover and opened channels for circulating ground waters. Preliminary warping is assumed because in the quiescent areas, near the center of the Delaware basin, salt was not dissolved even where all the Dewey Lake and the upper part of the Rustler had been stripped off. It is easy to date the trough as Triassic because any trough must be older than the over-thickened sediments that fill it and younger than the youngest sediments in which it occurs.

Pre-Cretaceous salt solution such as characterizes the Yates field[28] and Fort Stockton "high" areas has left no trace in the Delaware basin. The thick sections of Lower Cretaceous encountered in wells near the south end of the basin are beyond the original limits of the main salt section and are probably due to the filling-in of fault troughs or erosional depressions.

The main period of Delaware basin solution took place during the Tertiary. Solution appears to be limited to areas from which the Cretaceous cover had been removed. The main solution trough is roughly bordered on the east by the Pecos

[28] John Emery Adams, "Structural Development, Yates Area, Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 134–42.

River, and extends from Carlsbad, New Mexico, to Toyah Lake in Texas. Significantly, this is the area with the most pronounced development of porous Salado sandstones which probably acted as conduits for circulating waters. The isolated remnants of Salado salt, west of the Pecos River in northern Reeves County, would not be present if solution had simply started at the western outcrops and moved eastward. Areas of non-solution, such as those at Barstow and Mentone, seem to form buttresses that control the present course of the Pecos River.

Maximum depth of the synclinal solution trough is not known but southwest of Mentone it exceeds 1,300 feet. Much of the solution developing such a deep trough must have taken place below the level of the spillway over which the saturated waters escaped across the Edwards Plateau toward the southeast. This would imply that the sinking trough was filled with sediments as rapidly as it formed, and that solution occurred in a sealed hydrostatic system. If a deep lake had developed in the open valley behind the spillway and solution had depended on surface drainage, an insulating layer of brine would have accumulated in the deeper basins, next to the dissolving face of the salt. Incoming fresh waters would have flowed across the surface of the heavy brine layers without flushing them out and further solution would have been checked. With circulation maintained through the porous sands in the Salado section, which cropped out high on the Front Range at the northwest, and with the valleys continually filled with shales and sands from the Cretaceous highlands on the west, solution could continue as long as there was a sufficient head of water to force the brines up over the south rim. Probably the process is still in progress.

The most recent solution valley is the one now developing in the Nash Draw southeast of Carlsbad. Here solution is taking place along the unconformity at the base of the Rustler formation. Nash Draw itself appears to be an unfilled solution valley.[29] The great increase of salt in solution in the Pecos River water from the point where it starts across the Permian evaporites to the point where it flows out onto the Cretaceous is evidence of present rapid solution.[30]

Geologists unfamiliar with Upper Permian stratigraphy have suggested that the features described as solution troughs might be due to salt flowage. We have sufficient data to disprove this hypothesis. The basin-wide uniformity of salt and anhydrite strata of the Salado and of dolomites and anhydrites in the Rustler would be highly disrupted if the ridges and valleys were due to salt flowage. Instead they extend up to the very edges of the solution valleys without any break in uniformity.

HYDRATION AND SOLUTION OF CALCIUM SULPHATE

The calcium sulphate of the Ochoa series is represented by gypsum on the

[29] Thomas W. Robinson, "General Relations of the Geology to the Occurrence of Brine at the Base of the Rustler Formation," *New Mexico State Engineer 12th and 13th Bien. Rept.* (1934–1938), pp. 86–93.

[30] W. D. Collins and H. B. Riffenburg, "Quality of Water of Pecos River in Texas," *U. S. Geol. Survey Water-Supply Paper 596* (1927), pp. 67–88.

outcrops and in the subsurface to a depth of about 500 feet. Below this depth the gypsum is replaced by anhydrite. It is probable that the temperature of the brine from which the Ochoa evaporites were deposited was such that part of the calcium sulphate was originally deposited as gypsum. By applying the foregoing observations, it seems probable that by the time the original deposit had been buried to a depth of about 500 feet, the pressure became great enough to dehydrate the gypsum to anhydrite. Settling due to loss of volume by this change would be uniform over the entire basin. All the beds of the Ochoa series were buried deeply enough by post-Permian deposits to insure dehydration of the entire section. The gypsums now present at or near the surface have been hydrated since the removal of this load. Hydration took place irregularly with both lateral and vertical adjustments. A certain amount of solution accompanied the hydration and, as a result, numerous domes and solution synclines were developed. Some of these structures were tested for oil during the early development of the area, but all showed normal regional dip in the unhydrated, deeper beds. The hydration structures are more numerous than those produced by salt solution, but are smaller and less pronounced.

ECONOMIC IMPORTANCE

Economically the potash deposits of the upper Salado halite are the most important features of the Ochoa series. Rock salt, petroleum, and brine chemicals have also been produced. The outcrops are marked by a very inferior type of soil even for an arid area of low productivity. Perhaps to the petroleum geologist the Ochoa rocks of the Delaware basin, or even of the whole Permian basin, are most important as an effective mask for the structure of the underlying beds.

CONCLUSION

The purpose of the writer has been to describe the rocks of the Ochoa series as they occur in and adjacent to the Delaware basin. Discussions of origin and post-depositional history are largely theoretical and incidental. They were included to show that the evaporites that we now find could have been formed by specialized, natural processes from sea water differing in no important way from that of the present ocean.

No special attempt has been made to justify setting up the practically non-fossiliferous Ochoa as a Permian series equal in rank with the three older series of Permian rocks. Here we find a great mass of evaporites, greater in thickness and equal to, or greater in volume than, the evaporite equivalents of any of the three older Permian series, and we assume the presence of a fourth series of fossiliferous rocks somewhere, even though we can not exactly locate it; we name what we have, because a name is necessary, and leave the rest to the future.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1626-1634

MOOREFIELD FORMATION AND RUDDELL SHALE, BATESVILLE DISTRICT, ARKANSAS[1]

MACKENZIE GORDON, JR.[2]
Washington, D. C.

ABSTRACT

The Moorefield formation in the Batesville district, Independence County, Arkansas, consists of a lower member of black calcareous shale and limestone and an upper member of dark gray fissile clay shale. The lower member has been known as the Spring Creek limestone (name preoccupied) and grades laterally into chert that has been mapped incorrectly as Boone chert. It is recommended that the name Moorefield formation be restricted to the lower member, and that the name Ruddell shale be erected for the upper member. The fossil assemblages indicate that the Moorefield formation (restricted) represents the British P_1 (G_1) or *Goniatites crenistria* zone and the Ruddell shale together with the overlying Batesville sandstone, the P_2 (G_2) or *Goniatites striatus* zone of the upper Viséan stage of the European Carboniferous section. The Moorefield formation (restricted) is correlated tentatively with the St. Louis limestone and the Ruddell shale with the Ste. Genevieve limestone of the central Mississippi Valley section.

In the Batesville district in northeastern Arkansas there is a considerable sequence of dark gray to black calcareous shale, limestone, and fissile clay shale, overlying the Boone formation and underlying the Batesville sandstone. Because of its lithologic similarity to other parts of the Carboniferous section in northern Arkansas and of peculiarities of outcrop such as local secondary chertification and complication by faulting, this sequence has long presented a problem to the stratigrapher.

Early geologists of the Arkansas Geological Survey mapped the black shales and limestones under consideration as Fayetteville shale, believing them to be the same as those exposed widely in Washington County, Arkansas. In 1895, H. S. Williams[3] introduced the name "Spring Creek limestone" for the 18 feet of fossiliferous black limestone and shale exposed in the railroad cut near Ruddell's mill on Spring Creek. This name was later found to be preoccupied, and in 1904 Adams, Purdue, and Ulrich[4] proposed the term Moorefield shale for the beds between the Boone chert and the Batesville sandstone in the Batesville district, using the name "Spring Creek limestone member" for the calcareous beds at the base.

Girty visited the Batesville district in 1907 and again in 1908 and later wrote a comprehensive report on the fauna of the Moorefield shale.[5] He collected fossils from the top and base of the calcareous member and from the overlying fissile shale in the vicinity of Ruddell's mill on Spring Creek. He also made several collections from the section of black calcareous shale and limestone exposed on the

[1] Published with the permission of the director of the Geological Survey, United States Department of the Interior. Manuscript received, July 31, 1944.

[2] Associate geologist, United States Geological Survey.

[3] H. S. Williams, *Amer. Jour. Sci.*, 3d. Ser., Vol. 49 (1895), pp. 94–95.

[4] G. I. Adams, A. H. Purdue and E. O. Ulrich, *U. S. Geol. Survey Prof. Paper 24* (1904).

[5] G. H. Girty, *U. S. Geol. Survey Bull. 439* (1911).

G. A. Godfrey place (now owned by Rev. Hardin) about ½ mile southwest of Moorefield.

At a later time Girty made collections from the black calcareous shale exposed along the east bank of Spring Creek about a mile north of Ruddell's mill and from loose blocks from the overlying chert section. These beds had earlier been mapped as the Boone chert by Hopkins.[6] Girty reported on the fauna of "the so-called Boone chert"[7] and pointed out that it was the same as that of the calcareous member of the Moorefield formation.

The writer revisited Girty's localities in the fall of 1940, during the course of a stratigraphic study of the Carboniferous rocks of the Batesville district. As a result of this and subsequent paleontologic studies, the writer has arrived at the following conclusions.

1. The true thickness of the lower calcareous member of the Moorefield formation is not exposed at Ruddell's mill, the greater middle part being faulted out.

2. The missing section is composed principally of chert and is exposed along Spring Creek north of Ruddell's mill.

3. The black calcareous shale below the chert one mile north of Ruddell's mill marks the base of the Moorefield formation. This shale grades laterally into chert northward toward Limedale.

4. The entire section exposed on the Godfrey place near Moorefield belongs in the calcareous member, the top siliceous bed (Girty's "sandstone with *Deltopecten*") being the same as the impure siliceous limestone that marks the top of the Spring Creek limestone member of Adams and Ulrich at Ruddell's mill.

5. By far the greater part of the Moorefield fauna is confined to the calcareous member.

6. The goniatites of the upper fissile shales do not occur in the underlying calcareous member but do occur in the overlying Batesville sandstone. The calcareous member contains a different cephalopod fauna.

In the winter of 1943–44 the writer and D. M. Kinney made a geologic map of part of the Batesville district. This will appear shortly as a preliminary map[8] of the Oil and Gas Investigations series of the United States Geological Survey. The two members of the Moorefield formation were mapped separately. It is now proposed that the name Moorefield formation be restricted to the lower calcareous member and that the name Ruddell shale be erected for the upper fissile clay shale member.

MOOREFIELD FORMATION

DISTRIBUTION

The Moorefield formation is exposed north of the White River in two separate areas, one east and the other west of Batesville. In the vicinity of Moorefield

[6] T. C. Hopkins, *Arkansas Geol. Survey Ann. Rept. for 1890*, Vol. IV, atlas (1893).

[7] G. H. Girty, *U. S. Geol. Survey Bull. 595* (1915).

[8] This map is now published.
Mackenzie Gordon, Jr., and Douglas M. Kinney, "Geologic Map and Structure Sections of the Batesville District, Independence County, Arkansas," *U. S. Geol. Survey Prelim. Map 12*, Oil and Gas Inves. Ser. (1944).

it crops out on a number of low hills, with the top siliceous bed capping some of the higher hills and forming a gentle dip slope toward the south and west. This area is bounded on the north by an east-trending fault which lies in the valley of Miller and Moorefield creeks and passes along the north edge of the town of Moorefield. A mile west of Moorefield the fault brings the Ruddell shale and Batesville sandstone against the base of the Moorefield formation.

North of the Moorefield fault, in a graben block bounded on the north by the Pfeiffer fault, the Moorefield formation is exposed on a number of low hills around the east and north flanks of a broad syncline that plunges gently southwest. North of Gainesboro there are cherty beds in the formation. Northeast of Batesville the Moorefield formation is cut out by faulting.

West of Polk Bayou and north of the Pfeiffer fault the cherty facies caps many ridges in the area underlain by the Boone chert. The formation crops out south of the Pfeiffer fault only in the vicinity of Ruddell's mill, where the top and bottom calcareous beds are exposed, but most of the intervening section is cut out by a branch fault. West of Spring Creek the formation is exposed along the base of Bracy Mountain, in Mill Creek, and along the north base of the Bethesda plateau. The westernmost exposure is at O'Neal, on the White River.

CHARACTER

The Moorefield formation is composed principally of dark gray to black calcareous shale and limestone. The limestone generally is impure and weathers to a tan earthy material. The shale is platy and creaks when struck by a hammer. The middle part typically is less calcareous than the top and base.

Along the Pfeiffer fault the formation contains chert interbedded with the black shale and limestone. The chert is mainly of three types: a coarsely porous light to dark gray variety which appears blocky on weathering; a light tan finely porous highly fractured variety which splinters readily; and a dark gray to black dense variety. Some of the coarsely porous variety is horizontally banded. All three types are easily distinguishable from the thin-bedded vermicular chert common in the underlying upper member of the Boone chert. Moreover, the cherts of the Moorefield formation are more regularly bedded than those of the upper member of the Boone.

The amount of chert in the Moorefield formation increases north of the Pfeiffer fault until a point is reached where the entire thickness is chert. Similarly it decreases south of the Pfeiffer fault until there is no chert present in the formation. In general, the amount of chert in the formation varies directly with the elevation above sea-level and inversely with the amount of cover. Hence it appears that the chert is a product of the weathering of the formation as is the porous and vermicular chert of the Boone chert. This is further suggested by the fact that there is a direct relation between the type of chert derived from, and the nature of, the original limestone or shale present in the same bed.

The top of the formation is marked in most of the area by a bed of dark gray

impure siliceous limestone which weathers to a tan fine-grained grit. This bed is 8 feet thick at Ruddell's mill and 9 feet thick in the vicinity of Moorefield.

THICKNESS

In the Batesville district the Moorefield formation ranges in thickness from a thin edge to 200 feet. It thickens from northwest to southeast. In the Grigsby No. 1 well, drilled by the Walbert Oil Company, 200 feet north and 300 feet west of the center of Sec. 3, T. 12 N., R. 6 W., the formation is 199 feet thick. In the Pryor No. 1 well drilled by Hinkle and Fitzpatrick near the center of the SE. $\frac{1}{4}$, SE. $\frac{1}{4}$ Sec. 32, T. 13 N., R. 6 W., the thickness is 158 feet. At the Hardin ranch (old Godfrey place), near Moorefield, approximately 110 feet is exposed with the base concealed. On the west bank of Spring Creek just south of Limedale a thickness of about 125 feet is exposed with the top beds absent. West of Spring Creek the formation thins markedly within a rather short distance. At the base of the northwest slope of Bracy Mountain, along Mill Creek, it is 40 feet thick. At O'Neal the formation is 2 feet thick. One mile north of O'Neal on the east bank of the White River the Moorefield formation is absent and the Ruddell shale rests on the uneven surface of the Boone chert.

RELATION TO ADJACENT FORMATIONS

The contact between the Boone and Moorefield formations has not been observed in the eastern area of outcrop. Along Spring Creek the basal beds of the Moorefield appear to rest evenly on the surface of the Boone chert although the change from light gray limestone to black limestone and shale is markedly abrupt. In the western part of the area where the formation is thinner the upper surface of the Boone chert appears to be, locally at least, rather uneven. At O'Neal this surface is decidedly uneven and the relation between the two formations obviously is unconformable. As the Boone formation in the Joplin district contains beds with upper Warsaw and Spergen fossils that are known to be younger than the uppermost beds of this formation in the Batesville district, which are lower Warsaw in age, it is believed that there is a hiatus between this formation and the Moorefield formation representing probably all of upper Warsaw and Spergen time.

FOSSILS AND CORRELATIONS

Much of the Moorefield formation is sparsely fossiliferous and the fossils are poorly preserved. Locally, however, fossils are both abundant and well preserved. Except for the top siliceous bed the Moorefield fauna is found at all levels in the formation, and attempts to subdivide the formation further on a faunal basis appear impractical. A complete list of the known species in the formation is here given. It is based principally on Girty's two reports.[9] Those species that are believed to be restricted to this formation in Arkansas are marked with an asterisk (*).

[9] G. H. Girty, *op. cit.* (1911 and 1915).

Triplophylum sp.
**Enchostoma bicarinatum* Girty
**Batostomella dubia* Girty
Batostomella parvula Girty
Tabulipora sp.
Fenestella aff. *F. rudis* Ulrich?
Fenestella aff. *F. multispinosa* Ulrich?
Lingula batesvillae Girty
**Lingula albapinensis* Walcott
Orbiculoidea newberryi caneyana (Girty)
Orbiculoidea newberryi marshallensis (Girty)?
**Orbiculoidea newberryi moorefieldana* (Girty)
Orbiculoidea newberryi ovata (Girty)
Chonetes sp.
**Dictyoclostus fosteri* Sutton
Buxtonia multilirata (Girty)
**Linoproductus pileiformis latior* Snider
**Avonia oklahomensis* Snider
**Avonia* sp.
Pustula hirsutiformis (Walcott)
**Pustula hirsutiformis batesvillensis* (Girty)
**Pustula moorefieldana* (Girty)
**Pustula moorefieldana pusilla* (Girty).
**Pustula subsulcata* (Girty)
**Pustula subsulcata janus* (Girty)
**Rhipidomella arkansana* Girty
Leiorhynchus carboniferum Girty
Leiorhynchus carboniferum polypleurum Girty
Camarotoechia purduei Girty
**Camarotoechia purduei agrestis* Girty
Moorefieldella eurekensis (Walcott)
**Moorefieldella eurekensis subcuboides* Girty
Spirifer arkansanus Girty
Spirifer martiniiformis Girty
**Spirifer moorefieldanus* Girty
**Echinocoelia pilosa* (Girty)
Echinocoelia levicula (Rowley)?
**Punctospirifer* n. sp. aff. *P. fayettevillensis* (Girty)
Reticularia internascens Girty
Eumetria verneuilana (Hall)
**Composita globosa* Snider
Composita sp.
Solenomya? sp.
Sphenotus? meslerianus Girty?
Edmondia crassa Girty
Edmondia crassa suborbiculata Girty
Edmondia? sp.
Nuculopsis rectangula (McChesney)
**Nuculana nasuta* (Hall)?
Nuculana vaseyana (McChesney)
**Parallelodon multiliratus* Girty
**Cypricardinia moorefieldana* Girty
**Caneyella richardsoni* Girty
Posidonia vaughani (Girty)
**Euchondria caneyana* (Girty)
Aviculopecten batesvillensis Weller
**Allerisma walkeri abbreviatum* Girty
Cypricardella? sp.
**Pleurotomaria* aff. *P. carbonaria* Norwood and Pratten
Bembexia nodimarginata (McChesney)
Phanerotrema? sp.
**Trepospira?* n. sp.
Strobeus? sp.
Bellerophon sp.
Bucanopsis textilis (Hall)?
Straparollus (*Euomphalus*) *planidorsatus* (Meek and Worthen)
Platyceras? n. sp.
Mooreoceras aff. *M. crebriliratum* (Girty)
**Mooreoceras* sp. A
**Mooreoceras* sp. B
**Endolobus ornatus* Girty
**Bactrites carbonarius* Smith
Bactrites quadrilineatus Girty
Bactrites smithianus Girty?
**Goniatites choctawensis* Shumard
Griffithides sp.
Paraparchites nicklesi (Ulrich)
**Primitia moorefieldana* Girty
Bairdia attenuata Girty
Bairdia aff. *B. cestriensis* Ulrich

The United States Geological Survey's Carboniferous collection 1248R_4 which was among those studied by Girty in his report on the Moorefield fauna was not used in preparing the foregoing list, as it is a mixed lot of fossils from the Moorefield formation and from the Fayetteville shale. This caused the erroneous listing of *Diaphragmus elegans* (Norwood and Pratten), *Girtyella brevilobata* (Swallow), *Girtyella brevilobata marginalis* (Girty), and *Spirifer increbescens* Hall, species that are foreign to the Moorefield fauna. Girty discovered this error subsequent to the publication of the paper.

The uppermost siliceous bed in the vicinity of Moorefield contains *Moorefieldella eurekensis* (Walcott), *Leiorhynchus carboniferum* Girty, *Posidonia vaughani* (Girty) and *Aviculopecten batesvillensis* Weller. At Ruddell's mill this bed contains *Lingula batesvillae* Girty, *Aviculopecten batesvillensis* Weller and *Schizodus batesvillensis* Weller.

Goniatites choctawensis, which at the Hardin place occurs 20 to 40 feet below

the top of the formation, is equivalent to, and may even be conspecific with, *G. crenistria* Phillips, the marker of the P_1 (G_1) subzone of the *Posidonia* or *Goniatites* zone in the lower Bowland shale of northern England, and in apparently equivalent beds elsewhere in Europe and the U.S.S.R. Hence the Moorefield formation appears to represent the lower part of the upper Viséan stage in Europe.

Representatives of the Moorefield fauna are known also in the lower parts of the Caney shale of Oklahoma, the Barnett shale of central Texas, and the White Pine shale of eastern Nevada.

Most geologists have regarded the Moorefield fauna as approximately St. Louis in age. No additional information has been gathered that would invalidate the correlation of the Moorefield formation as restricted in this report with the St. Louis limestone of the Mississippi Valley, though direct evidence to support this correlation is still lacking.

RUDDELL SHALE

DEFINITION

The name Ruddell shale is here proposed for the section of fissile clay shales lying between the top siliceous limestone bed of the restricted Moorefield formation below and the base of the Batesville sandstone above. This section is well exposed on the west end of Ruddell Hill, in Ruddell civil township near Ruddell's mill. It is almost completely exposed along the Batesville-Bethesda road in the NE. $\frac{1}{4}$, NE. $\frac{1}{4}$ Sec. 13, T. 7 N., R. 13 W., starting in a gully a few feet below the culvert $\frac{3}{8}$ mile northwest of Ruddell's mill and continuing east and south to the crown of Ruddell Hill. The thickness of the shale is about 125 feet at this locality. The contact with the Batesville sandstone is concealed by slumped blocks of sandstone but is marked by a spring near the top of the hill.

DISTRIBUTION

The Ruddell shale is more widely exposed than the Moorefield formation. It crops out on the south bank of the White River south of Batesville, but the base is concealed by alluvium and by down-faulted Batesville sandstone. South of Moorefield it crops out on low hills along the Batesville-Newark road. In the syncline north of the Moorefield fault it occupies broad valleys between low hills. There are several patches of the shale exposed along the Pfeiffer fault. It is exposed on the north, east, and south slopes of the Batesville plateau, the north, west, and south slopes of Ruddell Hill, and around all the edges of Bracy Mountain, Childers Mountain, and the Bethesda plateau as well as in some stream valleys cut into the plateau. According to Croneis,[10] the westernmost exposure of the shale appears to be at St. Joe in Searcy County, Arkansas. Hopkins[11] however has mapped the shale as far as Mt. Judea in Newton County, Arkansas.

[10] Carey Croneis, *Arkansas Geol. Survey Bull. 3* (1930), p. 52.

[11] T. C. Hopkins, *Arkansas Geol. Survey Ann. Rept. for 1890* (1893), atlas.

CHARACTER

The Ruddell shale is typically dark gray to greenish gray, fissile clay shale which weathers to red clay. The lower 30–40 feet of shale contains arenaceous and calcareous beds some of which are platy and resemble shales of the Moorefield formation. The upper half of this interval contains dark gray to black limestone concretions, rather sparsely distributed, which contain a goniatite assemblage. Above this interval the shale is very fissile, except for a few poorly fissile layers, and contains irregularly shaped clay-ironstone nodules up to 6 inches across. In the middle part of the shale phosphatic nodules up to 2 inches in diameter are common and these contain cephalopods and pelecypods which weather out at the surface.

The upper 50 feet of shale ordinarily is not noticeably fossiliferous except at Earnharts Station on the north bank of the White River, 7 miles west of Batesville, where there are calcareous beds near the top. A section is exposed in the run back of the station as follows.

Description	*Thickness in Feet*
Batesville sandstone	
Ruddell shale	
f. Red, green, and gray poorly fissile shale, weathers tan	3.5
e. Dark gray fine-grained slightly fossiliferous limestone lens in calcareous shale	1.0
d. Dark gray to black fissile to platy shale	3.0
c. Dark gray fine-grained fossiliferous limestone, weathers to tan	2.0
b. Dark gray to black fissile to platy partly calcareous shale	3.0
a. Dark gray to greenish gray very fissile clay shale which weathers red and contains clay-ironstone concretions. Poorly exposed	54+

These calcareous beds have also been encountered in drill holes on the south side of the White River in the vicinity of Earnharts.

THICKNESS

Like the underlying Moorefield formation the Ruddell shale thickens southeastward. In the Grigsby No. 1 well the thickness encountered was 272 feet, and in the Pryor No. 1 well 243 feet. At the south end of the Ramsey Bottom viaduct (Arkansas State Highway 11), approximately 185 feet of shale is exposed with the lower 15–20 feet of the formation concealed by down-faulted Batesville sandstone. At the south end of the Miller Creek bridge (Arkansas State Highway 11) at the north edge of Batesville a complete section 165 feet thick is exposed. In the Hinkle well, drilled by the Batesville Oil and Gas Company, 180 feet south and 925 feet west of the center of Sec. 17, T. 13 N., R. 6 W., the thickness encountered was 149 feet. At the type locality on Ruddell Hill the shale, which is exposed near the axis of a small anticline close to the Pfeiffer fault, is 125 feet thick. Along the Batesville-Bethesda road, one mile east of Bethesda, the shale is 115 feet thick.

RELATION TO ADJACENT FORMATIONS

The Ruddell shale appears to overlie the Moorefield formation conformably wherever the contact can be observed. The presence of the uppermost siliceous bed

of the Moorefield over a wide area strongly suggests a conformable relationship. This bed, however, does not appear to be present in the vicinity of O'Neal, where the Ruddell shale overlaps the Moorefield formation and is exposed at the north, resting unconformably on the Boone chert.

The Batesville sandstone likewise appears to rest conformably on the Ruddell shale. Continuous deposition of the three formations is further suggested by the lack of any noticeable break in the sequence of goniatite assemblages as compared with other sections in the United States and Europe.

FOSSILS AND CORRELATIONS

The Ruddell shale is rather sparsely fossiliferous at most exposures. Locally, however, individuals are abundant though species are few. The calcareous beds 15 feet above the base of the formation at the type locality contain *Posidonia vaughani* (Girty). The phosphatic and clay-ironstone nodule beds 50–75 feet above the base of the formation are well exposed at the southwest end of Ruddell Hill in the first gully north of Cushman Junction Station. These beds contain *Mooreoceras crebriliratum* (Girty), *Goniatites kentuckiensis* Miller, *Neoglyphioceras subcirculare* (Miller), *Lyrogoniatites newsomi* (Smith) and *Dimorphoceras?* sp.

These beds are also exposed in the section at the highway bridge across Miller Creek, 55–70 feet above the base of the shale where the weathered out goniatites include *Goniatites kentuckiensis* Miller, *Neoglyphioceras subcirculare* (Miller) and *Girtyoceras limatum* (Miller and Faber).

In the Ramsey Bottom section at the south bank of the White River along Arkansas State Highway 11, the calcareous shale and limestone concretion beds are exposed 160–170 feet below the top of the shale. The shale contains *Caneyella percostata* Girty and *Goniatites kentuckiensis* Miller. The limestone concretions contain *Mooreoceras?* sp., *Goniatites kentuckiensis* Miller, *Lyrogoniatites newsomi* (Smith) and *Girtyoceras limatum* (Miller and Faber). In the same section the nodule beds are exposed 55–85 feet below the top of the shale and contain the following.

Caneyella percostata Girty
Aviculopecten batesvillensis Weller?
Mooreoceras sp.
Goniatites kentuckiensis Miller
Neoglyphioceras subcirculare (Miller)
Girtyoceras limatum (Miller and Faber)

The *Goniatites kentuckiensis* fauna, which occurs in the Ruddell shale and in the overlying Batesville sandstone, is equivalent to the *Goniatites striatus* subzone P_2 (G_2) of the *Posidonia* or *Goniatites* zone of northern England and equivalent beds of the upper Viséan stage elsewhere in western Europe, in the U.S.S.R., and in northern Africa. Thus the Ruddell shale apparently represents the middle and the Batesville sandstone the top of the upper Viséan. The *G. kentuckiensis* fauna is also known to occur in the Floyd shale of Georgia, the Caney shale of Oklahoma, the Barnett shale in north-central Texas, and unidentified beds in the vicinity of Crab Orchard, Rockcastle County, Kentucky.

The fauna of the calcareous beds at the top of the Ruddell shale at Earnharts

Station shows a strong relationship to the fauna of the overlying Batesville sandstone. Referring to the foregoing section for this locality, the lower 3 inches of bed b contains *Chonetes tumescens* Easton, *Buxtonia arkansana* (Girty) and *Goniatites kentuckiensis* Miller. Bed c contains the following fauna.

Orthotetes subglobosus batesvillensis Girty
Buxtonia arkansana (Girty)
Linoproductus pileiformis (McChesney)
Camarotoechia purduei Girty
Eumetria verneuilana (Hall)
Cleiothyridina elegans Girty
Composita subquadrata Hall
Sphenotus vulgaris Girty
Yoldia levistriata (Meek and Worthen)?
Caneyella hopkinsi (Weller)
Myalina elongata Girty
Allerisma walkeri Weller var.
Aviculopecten? sp. indet.
Mooreoceras sp.

The upper 4 inches of bed e contains the following.

Lingula batesvillae Girty
Camarotoechia purduei Girty
Eumetria verneuilana (Hall)
Composita subquadrata (Hall)?
Myalina elongata Girty
Naticopsis splendens (Girty)

All of these species except *Chonetes tumescens* occur in the overlying Batesville sandstone. However, the form identified here as *C. tumescens* is common in the Batesville sandstone in the Wyandotte Quadrangle of Oklahoma and is presumably the same as the form described by Easton from the Pitkin limestone. Only three of the species are known to occur in the underlying Moorefield formation.

Despite the close relationship of the fauna of the Ruddell shale and the Batesville sandstone, the shale is here considered tentatively to be equivalent to the Ste. Genevieve limestone of the Mississippi Valley. Diagnostic Chester genera such as *Productus* (*Diaphragmus*) and *Agassizocrinus* are not known below the base of the Batesville sandstone. Though their absence may be controlled by a difference in facies the evidence still points to the Batesville sandstone as the basal formation of Chester age in the Batesville district.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1635-1641, 1 FIG.

SALT DIFFUSION IN WOODBINE SAND WATERS, EAST TEXAS[1]

C. W. HORTON[2]
Cambridge, Massachusetts

ABSTRACT

The distribution of sodium chloride in the waters of the Woodbine sand in East Texas is examined quantitatively. The salt distribution west of the Mexia fault implies an effective coëfficient of diffusion of approximately 300 times the normal value. This increase is explained by the presence of convection currents the possibility of which has been demonstrated elsewhere. The observed salt concentration around the Boggy Creek salt dome is explained on the basis of diffusion from a cylindrical source.

Plummer and Sargent[3] have assembled the results of a large number of analyses of the waters of the Woodbine sand of East Texas. They show a map[4] of the isosalinity contours, and they thoroughly discuss the possible causes of the abnormal concentration of salt. They state[5] that

the final causes of abnormal concentration may be summarized as follows.

1. Trapping of original sea water in pockets due to pinching out of a sand or cutting off of circulation as a result of folding or faulting.
2. Presence of a lense or plug of salt or other soluble compounds with which the water comes in contact.
3. Vertical migration of saline water upward along a fault, or open joint, or a fracture line from a deeper source into a water sand of less salinity.
4. Local heating of underground waters by vulcanism or other causes, which will increase the solubility of the water and hence increase its mineral content.

In this paper causes No. 2 and No. 3 are examined quantitatively.

With regard to cause No. 3, Plummer and Sargent, state,[6]

the migration from a deeper source may explain the higher concentration of salts in the Woodbine waters along the faults. Many of the faults are normal gravity faults, and along these planes of slipping openings or crevices may have furnished passages for deeper and more mineralized waters. . . . The evidence of such upward water movement is seen in veins of aragonite, calcite, and limonite, which occur in the fault zone.

In view of the subsequent discovery of the 1,000-foot column of Eagle Mills salt in Limestone County,[7] this explanation seems particularly plausible.

After the saline water has entered the sand there are two processes by which the salt can be distributed horizontally through the formation. One is diffusion, and the other is the effect of convection currents that result from the earth's thermal gradient. It has been shown elsewhere[8] that in the region west of the

[1] Manuscript received, August 28, 1944.

[2] Underwater Sound Laboratory, Harvard University.

[3] F. B. Plummer and E. C. Sargent, "Underground Waters and Subsurface Temperatures of the Woodbine Sand in Northeast Texas," *Univ. Texas Bull. 3138* (1931).

[4] *Ibid.*, Pl. VIII.

[5] *Ibid.*, pp. 54–55.

[6] *Ibid.*, p. 55.

[7] Ralph W. Imlay, "Lower Cretaceous and Jurassic Formations of Southern Arkansas," *Arkansas Geol. Survey Inform. Cir. 12* (1940), p. 14.

[8] F. T. Rogers and C. W. Horton, *Ms.*

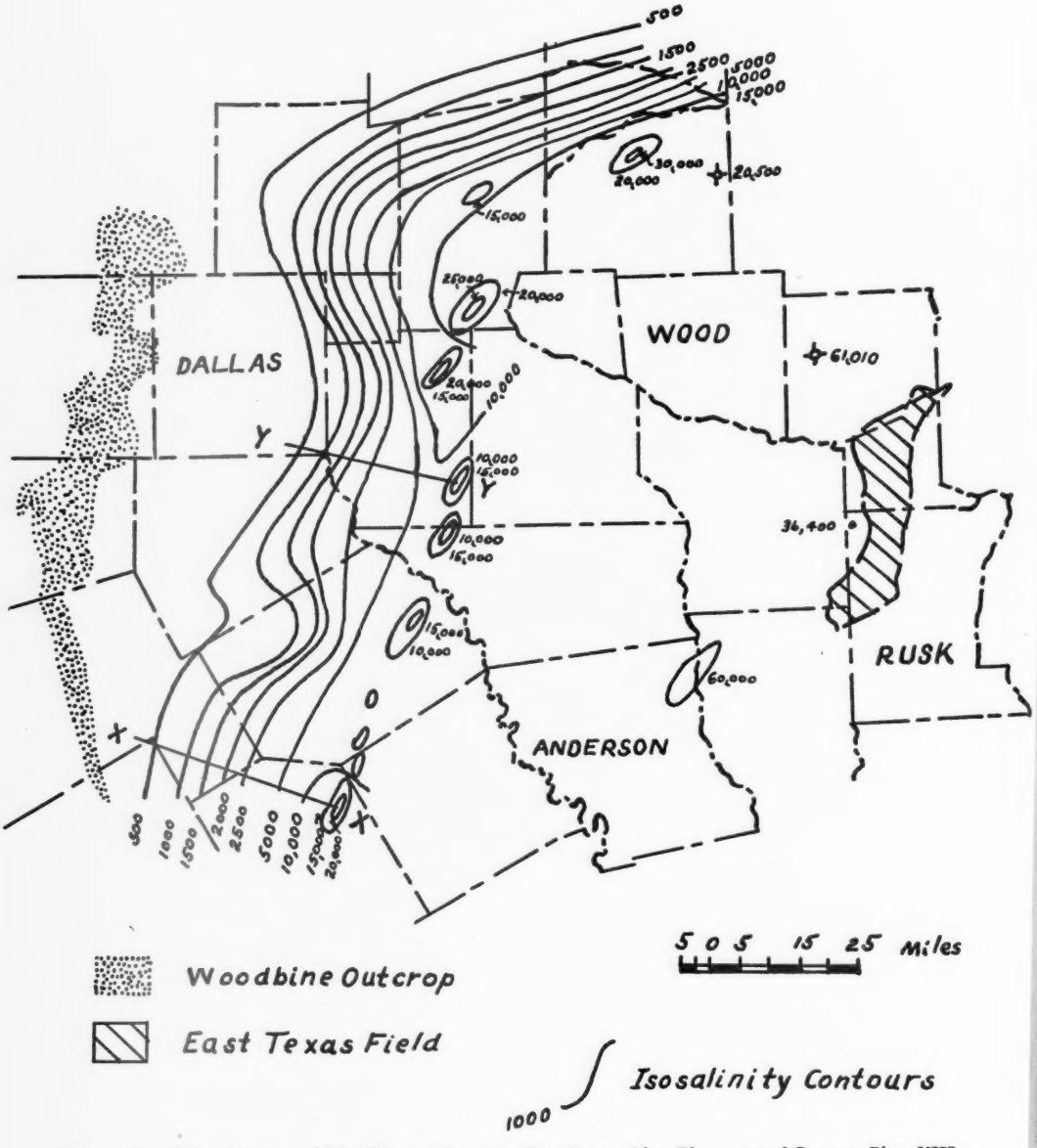


FIG. 1.—Isosalinity contours of Woodbine sand waters, East Texas. After Plummer and Sargent, Plate VIII.

Mexia fault zone the thermal gradient is sufficiently large to produce convection currents in the waters of the Woodbine sand.

Plate VIII of Plummer and Sargent's work is reproduced here as Figure 1. This map of the isosalinity contours shows that from Limestone County on the south to Hunt County on the north, a distance of approximately 80 miles, the fault zone and the isosalinity contours form nearly straight parallel lines. This indicates that the diffusion of the salt may be treated as a problem in one dimension.

We shall suppose that initially the waters of the Woodbine sand were free of salt (NaCl) but that from the time of the formation of the Mexia fault zone until the present day salt has been entering the Woodbine water at a constant rate. For the purpose of analysis one may consider the Woodbine sand to extend infinitely far, and, in the preliminary work, the effect of the convection currents will be neglected.

The concentration of chlorine in parts per million, $n(x, t)$, is assumed to satisfy the following differential equation and boundary conditions.

$$\frac{\partial n(x, t)}{\partial t} = k \frac{\partial^2 n(x, t)}{\partial x^2} \tag{1}$$

$$n(x, o) = o, \qquad o \leqq x \tag{2}$$

$$k \frac{\partial n(o, t)}{\partial x} = - A_0, \qquad o \leqq t \tag{3}$$

where

x = distance from the fault zone
t = time measured from the formation of the fault zone
k = diffusion coëfficient of the salt in the Woodbine water
A_0 = rate of entry of the salt into the formation.

The function

$$n(x, t) = - \frac{A_0}{k} x = - Ax \tag{4}$$

satisfies the boundary condition (equation 3); therefore, in accordance with a common procedure, one looks for a new function $v(x, t)$ that satisfies equation 1 and the new boundary conditions

$$v(x, o) = + Ax, \qquad o \leqq x \tag{5}$$

$$k \frac{\partial v(o, t)}{\partial x} = o, \qquad o \leqq t. \tag{6}$$

Carslaw[9] gives the solution to this problem as

[9] H. S. Carslaw, *Mathematical Theory of the Conduction of Heat in Solids* (1921), p. 35.

$$v(x, t) = \frac{1}{2\sqrt{\pi kt}} \int_0^\infty (A\xi) \left\{ e^{-(x-\xi)^2/4kt} + e^{-(x+\xi)^2/4kt} \right\} d\xi. \tag{7}$$

This can be integrated and one arrives at the solution

$$n(x, t) = \frac{2A}{\sqrt{\pi}} \left[\sqrt{kt} e^{-x^2/4kt} - x \int_{x/2\sqrt{kt}}^\infty e^{-\xi^2} d\xi \right]. \tag{7}$$

At $x = 0$

$$n(o, t_p) = 2A \sqrt{\frac{kt_p}{\pi}}$$

where t_p is the present time. Denote $x/2\sqrt{kt_p}$ by z and equation 7 may be written

$$\frac{n(x, t_p)}{n(o, t_p)} = e^{-z^2} - 2z \int_z^\infty e^{-\xi^2} d\xi. \tag{8}$$

Equation 8 is applied to three profiles. Two of these profiles, which are shown in Figure 1 as X–X and Y–Y, are 30 miles long and are on the west or downthrown side of the fault. The third, Z–Z, is only 4,000 feet long and is on the east or upthrown side of the Powell field fault. This last set of data is given by Plummer and Sargent in their Figure 8.[10] These data are here analyzed in Tables I, II, and III, respectively.

TABLE I

PROFILE X–X, WEST FROM MEXIA FIELD

x Kms	$n(x, t_p)$ PPM	$n(x, t_p)/n(o, t_p)$	$z = x/2\sqrt{kt_p}$	$x/z = 2\sqrt{kt_p}$
0	23,900	1.000	0	—
1.33	20,000	0.836	0.099	1.350×10^6
2.82	15,000	0.627	0.244	1.156
8.75	10,000	0.418	0.427	2.045
16.0	5,000	0.209	0.710	2.245
26.7	2,500	0.1047	0.949	2.82
31.2	2,000	0.0836	1.018	3.07
36.8	1,500	0.0627	1.10	3.34
43.0	1,000	0.0418	1.23	3.46
52.7	500	0.0209	1.4	3.76
			Aver.	2.58×10^6

TABLE II

PROFILE Y–Y, WEST FROM KAUFMAN COUNTY

x Kms	$n(x, t_p)$ PPM	$n(x, t_p)/n(o, t_p)$	$z = x/2\sqrt{kt_p}$	$x/z = 2\sqrt{kt_p}$
0	22,000	1.000	0	—
0.895	20,000	0.910	0.050	1.79×10^6
1.790	15,000	0.681	0.205	0.87
2.96	10,000	0.455	0.391	0.76
11.90	5,000	0.2275	0.677	1.76
23.8	2,500	0.1139	0.930	2.56
28.2	2,000	0.0910	1.005	2.80
32.7	1,500	0.0681	1.090	3.00
37.2	1,000	0.0455	1.215	3.06
43.1	500	0.0228	1.400	3.08
			Aver.	2.30×10^6

[10] F. B. Plummer and E. C. Sargent, *op. cit.*, Fig. 8, p. 56.

TABLE III

PROFILE Z–Z, EAST FROM POWELL OIL FIELD. TOTAL SOLIDS

x Kms	$n(x, t_p)$ PPM	$n(x, t_p)/n(o, t_p)$	$z=x/2\sqrt{kt_p}$	$x/z=2\sqrt{kt_p}$
0	18,290	1.000	0	—
0.0915	17,190	0.940	0.033	0.277×10^6
0.244	15,750	0.862	0.080	0.305
0.274	15,250	0.850	0.089	0.308
0.487	13,880	0.759	0.152	0.320
0.975	12,310	0.675	0.210	0.465
1.190	11,940	0.654	0.227	0.525
				Aver. 0.366×10^6

TABLE IV

Profile	*Av.* $2\sqrt{kt_p}$	kt_p	k *cm²/day*
X–X	2.58×10^6	1.66×10^{12}	166
Y–Y	2.30	1.32×10^{12}	132
Z–Z	0.366	3.35×10^{10}	3.35

These data are analyzed in Table IV. It is assumed that the fault has been in existence for 10^{10} days or just under 30 million years. The coëfficient of diffusion of sodium chloride in water is 0.94 cm.²/day, but when the water is in a porous medium, the diffusion coëfficient will be considerably reduced. The coefficients of diffusion of the other salts in the Woodbine waters are of the same order.

The distribution of the salt in the Woodbine sand waters west of the Mexia fault zone may be adequately explained by diffusion if the effective coëfficient of diffusion of the salt is approximately 250–300 times its normal value. This factor can be explained by convection currents which will greatly increase the rate of distribution of the salt through the water.

It has been shown elsewhere[11] that convection currents can exist in this formation and these data supply evidence that they do exist. The data of profile *Z–Z*, which are based on the distribution of total solids, show a much smaller value of k. This implies that convection currents have been much less pronounced in this region than on the west side of the fault.

The differential equation 1 can be restated in such a way that the effects of the convection currents are introduced. However, the resulting equation is considerably more complicated and its solution is deferred to a later paper.

The salt domes in the center of the embayment where the dip is small and convection probably does not occur offer a better test of the diffusion theory.

If a cylindrical source of salt has existed from time $t=0$ to the present, the distribution of the salt is given by Carslaw[12] as

$$n(r, t) = \frac{Q}{4\pi k}\int_0^t \frac{e^{-a^2+r^2/4k(t-\lambda)}}{(t-\lambda)}\, J_0\left\{\frac{iar}{2k(t-\lambda)}\right\} d\lambda \qquad (9)$$

where $n(r, t)$ = concentration of salt at time t and distance r

[11] F. T. Rogers and C. W. Horton, *op. cit.*

[12] H. S. Carslaw, *op. cit.*, p. 153.

Q = strength of the source, assumed constant
k = coëfficient of diffusion.

If the variable of integration is changed by $t-\lambda=1/u$, equation 9 becomes

$$n(r, t) = \frac{Q}{4\pi k}\int_{1/t}^{\infty} \frac{e^{-(a^2+r^2)u/4k}}{u} J_0\left\{\frac{iaru}{2k}\right\} du. \tag{10}$$

Over the range of integration one may, to good approximation, put

$$J_0(ix) = \frac{1}{\sqrt{2\pi x}} e^{+x} \tag{11}$$

and so equation 10 becomes

$$\frac{n(r, t)}{n_0} = \tfrac{1}{2}\sqrt{\frac{a}{nt}}\int_{1/t}^{\infty} \frac{e^{-(r-a)^2u/4k}}{u^{3/2}} du \tag{12}$$

where n_0 is the concentration of the salt solution at the face of the salt dome at the time t.

In deriving this solution it is assumed that the mechanism of solution is the following: when the salt dome is formed, the outer zones of the salt become hardened by the friction and pressure while the geologic strata become distorted and perhaps partly sealed from the salt. Thus the entry of the salt into solution is impeded and one may, as in the case of the fault zone, assume that the salt enters the water at a constant rate. This is described by equation 9. Since diffusion is a slow process, the salt is entering the water at a greater rate than it is moving away from the dome and n_0 increases as $t^{1/2}$. In the following numerical example it is assumed that n_0 has nearly the value for a saturated solution. When n_0 reaches the value for a saturated solution, equation 12 will cease representing the salt distribution and in its place one must use the solution corresponding with a constant concentration at the surface of the salt dome.

Equation 12 represents the distribution of salt in the water surrounding a circular salt dome. When more water analyses are available the theoretical distribution can be checked against the observed data. The only salt dome for which Plummer and Sargent give more than one observation is the Boggy Creek salt dome of Anderson and Cherokee counties. Although this dome is long and narrow and should be treated as an elliptical source, it is believed that in view of the small amount of data, the salt distribution around the end of the dome may be adequately treated by assuming that it has as a source a cylinder whose diameter is equal to the minor axis of the dome.

One has approximately $a=0.31$ mile ($=0.5$ kilometer) and $r=0.93$ mile ($=1.5$ kilometers). If we take $t=10^{10}$ days and $k=\frac{1}{2}$ cm.^{2}/day, equation 12 becomes

$$\frac{n}{n_0} = \frac{1}{\sqrt{12}}\int_{1}^{\infty} \frac{e^{-0.5u}}{u^{3/2}} du. \tag{13}$$

The integral, when evaluated by means of a planimeter, gives $n/n_0 = 0.122$. If the concentration of the salt solution at the boundary of the salt dome, n_0, is 390,000 PPM, then $n = 48{,}000$ PPM. This is in fair agreement with the observed values which range from 60,000 to 68,000 PPM.

Thus, the processes of diffusion and convection adequately explain the distribution of salt in the Woodbine waters. Although the presence of connate water is not disproved, the salt concentrations may be explained otherwise. Plummer and Sargent[13] consider the salt concentration to increase continuously from west to east. Very few analyses were made in the center of the basin and of these only the sample in Rusk County can not be explained by its nearness to a salt dome. There does not seem to be sufficient data to conclude necessarily that the salinity of the water is comparable with that of sea water throughout the basin.

[13] Plummer and Scott, *op. cit.*, Fig. 4, p. 46.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1642-1648, 1 FIG.

GEOLOGICAL NOTES

FUSULINIDS IN LA QUINTA FORMATION, VENEZUELA[1]

H. P. SCHAUB[2]
Maracaibo, Venezuela

On a recent excursion to the state of Trujillo a calcareous conglomerate was found in the basal part of the La Quinta formation. It is mainly composed of pebbles of a light gray limestone, some of which contain small gastropods, stems of crinoids, and fusulinids.

Outcrops of the conglomerate, which is 2 meters thick, occur along the new

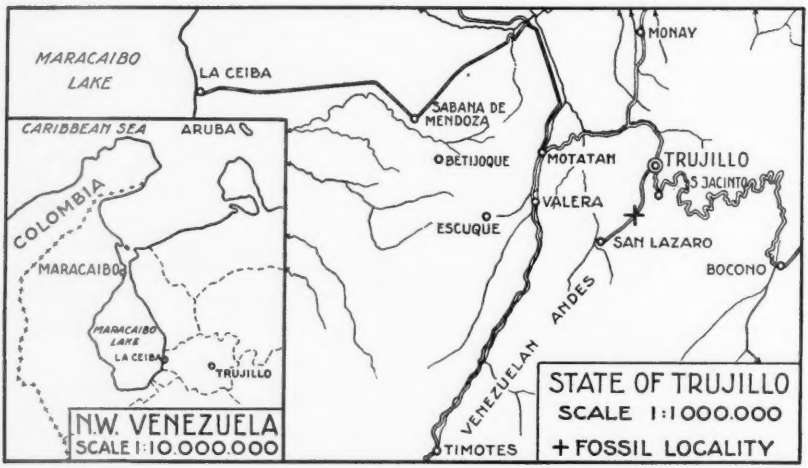


FIG. 1

road from Trujillo to San Lázaro, between Kilometers 10 and 16. Tectonically they are situated in the northwest flank of the southwest-striking San Jacinto syncline which is a part of the mountain system known as the Venezuelan Andes. The conglomerate is overlain by 1 meter of gray, quartzitic sandstone. Although the contact is nowhere exposed, it is nevertheless clear from the regional occurrence of the outcrops that the conglomerate lies unconformably on metamorphic schists of the Mucuchachí formation (probably Devonian). The bed forms the basal zone of a thick series of characteristically brick-red sandstones, conglomer-

[1] Manuscript received, October 2, 1944. Published by permission of the Caribbean Petroleum Company.

[2] Geologist, Caribbean Petroleum Company.

ates, and sandy shales, in which small lenses of coal occur. This series, which is called La Quinta or sometimes Girón formation, is itself overlain unconformably by the Tomón formation (Lower Cretaceous).

The fusulinids are not too well preserved but they are unmistakable. H. Baggelaar, paleontologist for the Caribbean Petroleum Company in Maracaibo, who examined them, is of the opinion that they show an alveolar (schwagerinid) type of test and belong to the subfamily Schwagerininae. This indicates Middle Pennsylvanian to Permian age.

H. D. Hedberg draws the writer's attention to the fact that fusulinids were found in several places in Venezuela. Thus H. Gerth[3] has figured and described *Fusulina* cf. *verneuili* von Möller from Paso Palmarito in the state of Mérida. This occurrence is discussed by Thompson[4] who assigns the specimen to *Schwagerina* or possibly *Parafusulina* and considers it to be indicative of Permian age. Hedberg and Sass[5] mention that *Fusulina*-bearing rocks of Carboniferous age have been reported from the upper course of Rio Palmar in the Perijá Mountains west of Maracaibo (state of Zulia). This statement was based on material shown to Hedberg by F. Hodson[6] and recorded by the latter as *Fusulinella* cf. *compressa* from the upper course of Caño Pescado, a northern tributary of Rio Palmar.

A further occurrence of fusulinid limestones is reported by Trümpy[7] from Rio Mula on the Colombian side of the Perijá Mountains. It is interesting to note that they are found there under similar conditions as in the state of Trujillo, namely, as boulders in conglomerates which belong to a thick series of redbeds. The Permian species, *Paraschwagerina yabei* (Staff) was determined from this locality.

It is probable that the fusulinid limestones of Trujillo belong to the Palmarito formation which has been described from several places in the Venezuelan Andes by Christ[8] and Kehrer.[9] This formation includes fossiliferous limestones, and their age has been determined as Upper Carboniferous to Permian. Gerth reported *Fusulina* cf. *verneuili* from the type locality of the formation as already mentioned.

The presence of fusulinid-bearing limestone pebbles at the base of the La Quinta formation is evidence for the transgressive character of the formation and defines its age as probably post-Permian. Based on all information available from

[3] H. Gerth, "Neue Vorkommen von marinem Oberkarbon in den nördlichen Anden, *Neues Jahrbuch f. Miner., Geol. und Palaeont.*, Vol. 65, Abt. B (1931).

[4] M. L. Thompson, "Permian Fusulinid from Peru," *Jour. Paleon.*, Vol. 17, No. 2 (1943).

[5] H. D. Hedberg and L. C. Sass, "Synopsis of the Geologic Formations of the Western Part of the Maracaibo Basin," *Venezuela Bol. de Geología y Minería*, t. 1, nos. 2–4 (Caracas, 1937).

[6] Communication by H. D. Hedberg.

[7] D. Trümpy, "Pre-Cretaceous of Colombia," *Bull. Geol. Soc. America*, Vol. 54 (1943), pp. 1281–1304.

[8] P. Christ, "Coupe géologique le long du chemin de Mucuchachí à Sta. Barbara dans les Andes vénézuéliennes," *Eclog. Geol. Helvetia*, t. XX (1927), pp. 397–414.

[9] L. Kehrer, "Some Observations on the Stratigraphy in the States of Táchira and Mérida, S.W. Venezuela," *Venezuela Bol. Geol. y Min.*, t. 2, nos. 2–4 (Caracas, 1938).

the Venezuelan Andes, much of which has been given by Kündig,[10] it can be said that the La Quinta formation may range from Triassic to Jurassic, possibly including both. Its sedimentation was preceded by strong orogenic movements probably belonging to the Hercynian phase which were accompanied by intense regional metamorphism as apparent in the Mucuchachí formation. The resulting mountain ranges were levelled by erosion and the débris deposited as the La Quinta formation which transgresses the older beds. New but less tectonic movements set in after its deposition and in many places it was completely eroded. Sedimentation began again during the Lower Cretaceous which transgresses the La Quinta formation and older beds.

AMMONOIDS FROM UPPER CHERRY CANYON OF DELAWARE MOUNTAIN GROUP IN TEXAS[1]

R. L. CLIFTON[2]
Enid, Oklahoma

The economic importance of additional oil and gas reserves by deeper drilling, from the Permian and from older Paleozoic rocks in West Texas, has prompted the writer to re-examine and to study the Paleozoic outcrops in West Texas and in southeastern New Mexico. These studies as planned, relate to geological factors involving stratigraphy, stratigraphical relationships, and paleontology.

On one of such surveys in August, 1944, the writer accompanied by R. V. Hollingsworth studied outcrops of the middle and the upper formations of the Delaware Mountain group that are excellently exposed in the Delaware Mountains, east and southeast of, and adjacent to, Guadalupe Peak in Texas. At one locality, an interesting ammonoid fauna with other invertebrates was collected from the Manzanita limestone member of the Cherry Canyon formation[3] which caps the top of Long Point, a structural and topographical feature[4] about 7 miles southeast of Guadalupe Peak. According to King, the Manzanita is the uppermost member of the Cherry Canyon formation of the Delaware Mountain group.

At the Long Point locality the writer collected ten or more species of ammonoids, chiefly from the lower half of the limestone member, although ammonoids appear to be distributed throughout the thickness of the Manzanita at this locality. The Manzanita limestones are dark, commonly siliceous, and locally interbedded with thin, more or less lenticular strata of calcareous shales, which suggest

[10] E. Kündig, "The Pre-Cretaceous Rocks of the Central Venezuelan Andes with Some Remarks about the Tectonics," *ibid.*

[1] Manuscript received, September 6, 1944.

[2] Geologist, Champlin Refining Company.

[3] Philip B. King, "Permian of West Texas and Southeastern New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26 (April, 1942), pp. 576–91, 597–608.

[4] Philip B. King, *op. cit.* (1942), p. 581, Fig. 3, p. 552.

that they are the weathered products of volcanic ash.[5] In one of such weathered strata, the ammonoid occurrence is abundant. The following ammonoids are recognized from the Manzanita limestone member at the Long Point locality.

Medlicottia sp.
Paraceltites ornatus Miller & Furnish
Cibolites uddeni Plummer & Scott
Pseudogastrioceras altudense (Böse)
Pseudogastrioceras roadense (Böse)
Pseudogastrioceras beedei (Plummer & Scott)
Pseudogastrioceras cf. *P. texanum* Clifton
Agathiceras girtyi Böse
Waagenoceras guadalupense Girty
Waagenoceras dieneri Böse
Waagenoceras richardsoni Plummer & Scott
Timorites? sp.

The species that compose this ammonoid fauna have been described elsewhere,[6,7] either from the Getaway or from the South Wells limestone members of the Cherry Canyon or from the Hegler, the Pinery, or the Rader limestone members of the overlying Bell Canyon[8] formation. The writer has collected *Pseudogastrioceras roadense* (Böse) from the Dog Creek formation and *Pseudogastrioceras texanum* Clifton from both the Blaine and Dog Creek formations, which crop out on the east side of the Permian basin in north-central Texas. The *Medlicottia* specimen from the Manzanita limestone appears to be closely related to a medlicottid collected by the writer from the Blaine and Dog Creek formations, though first noted there by Plummer and Scott.

The ammonoids at the Long Point locality are associated with brachiopods, pelecypods, sponges, a gastropod, a crinoid, and an echinoid. So far as the writer is aware, the Manzanita ammonoids have not been noted by other geologists, from strata of the limestone member. However, Roth[9] has noted the occurrence of fusulinids and other invertebrates in Manzanita strata at the type locality for this member and at other localities in the Delaware Mountains.

R. V. Hollingsworth made extensive collections of the Manzanita fusulinids at the type locality, Nipple Hill. Hollingsworth is now studying these fusulinids. Doubtless, his forthcoming announcement will include descriptions of them.

The invertebrate fossils that occur in the Manzanita limestone member, complete a faunal sequence for the upper Cherry Canyon formation, although King states:[10]

> Above the South Wells is a paleontological gap several hundred feed thick that extends to the Hegler limestone member at the base of the succeeding Bell Canyon formation. No

[5] Philip B. King, *op. cit.* (1942), p. 581.

[6] F. B. Plummer and Gayle Scott, "Upper Paleozoic Ammonites in Texas," *Univ. Texas Bull. 3701* (July, 1937), pp. 11–410.

[7] A. K. Miller and W. M. Furnish, "Permian Ammonoids from the Guadalupe Mountain Region and Adjacent Areas," *Geol. Soc. America Spec. Paper 26* (1940), pp. 1–242.

[8] Philip B. King, *op. cit.* (1942), pp. 581–86.

[9] Robert I. Roth, personal communication to the writer.

[10] Philip B. King, *op. cit.* (1942), p. 599.

fossils have been collected in the intervening beds, although poorly preserved specimens have been seen in the Manzanita limestone member.

It is believed that the ammonoids and other invertebrates, from the Manzanita limestone member of the Cherry Canyon formation, may be important to Permian stratigraphy and to correlation.

SOUTH TYLER FIELD, SMITH COUNTY, TEXAS[1]

T. E. WEIRICH[2]
Bartlesville, Oklahoma

A new oil and gas field has been opened in Smith County, Texas, by the Phillips Petroleum Company in the completion of its McMinn No. 1. On July 4, 1944, the test was completed as an oil well from casing perforations at 9,918–9,929 feet. The official Texas Railroad Commission test was 281.08 barrels of oil in 24 hours through 10/64-inch choke. The gas-oil ratio was 6040:1, the gravity 45.8° *Bé.*, and the tubing pressure 4,646 pounds.

History of exploration.—An anticline, trending north and south, appeared to exist south of Tyler in the subsurface, determined by test wells in the area. The fold apparently was bounded on the east by a syncline containing three salt domes, Bullard, Whitehouse, and Tyler, and on the west by steep west dip as indicated by subsurface markers. The deepest part of the Tyler basin, an Upper Cretaceous and Tertiary feature, is only 5 or 6 miles west of the fold.

The presence of the anticline was later checked by core drilling and reflection seismograph. The approximate top of the Reklaw, a Tertiary formation, was used as a datum in the core drilling. The average depth of the core-drill holes was 800 feet. The area was mapped from seismograph reflections in the upper part of the Comanche, found at approximately 6,000 feet.

History of exploitation.—McMinn No. 1 is 660 feet south and west of the NE. corner, NW. ¼ of the Mary M. Long Survey (Abst. 562), approximately 5 miles south of Tyler.

The hole was spudded, October 17, 1943, and drilling was completed to the total depth of 10,001 feet on March 24, 1944.

Subsurface markers as determined by electric log are as follows.

	Depth in Feet
Top Pecan Gap	3,610 (−3,132)
Base Austin	4,883 (−4,405)
Top Woodbine	5,150 (−4,672)
Top Goodland	7,267 (−6,789)
Top Paluxy	7,423 (−6,945)
Base Massive	
Base Anhydrite	9,395 (−8,917)
Top "James"?	9,863 (−9,385)
Base "James"?	9,960 (−9,482)

[1] Manuscript received, September 17, 1944.

[2] Geologist, Phillips Petroleum Company.

Oil began showing in the pits while drilling was at about 8,000 feet. For this reason, the well was shut in for a brief period, to condition the mud. Surface pressure built up to 1,000 pounds in 7 hours, and 11 barrels of 35° oil with considerable gas were bled off in 55 minutes. This oil occurred in the lower part of the Paluxy formation.

At 9,863 feet, soft gray, porous limestone, coquinoid in character, was encountered. This material was cored from 9,865 to 9,929 feet. Coring time averaged 5 minutes per foot in this section. Analyses of these cores showed an average porosity of 16 per cent. Porous limestone continued to be drilled from 9,929 to 9,960 feet but drilling time decreased to 25–30 minutes per foot.

This limestone section contained an odor of oil and gas throughout. Ether cuts of rock samples yielded sufficient color to indicate the presence of oil in the formation.

The producing section has been provisionally identified as the James limestone of lower Glen Rose age.

The areal extent of the field is, at present, indeterminate. McMinn No. 1 is located near the top of the anticline and possibly well within a gas cap. Deeper possibilities, particularly the Pettit limestone and sands of the Hosston formation remain to be tested.

SAND FLAT FIELD, SMITH COUNTY, TEXAS[1]

L. D. BARTELL[2]
Shreveport, Louisiana

The Sand Flat field is located 7 miles north of Tyler in Smith County, Texas. It is 5 miles northwest of the Tyler salt dome and 5 miles southeast of the Steen salt dome. It is 9 miles northwest of the Chapel Hill field, 9 miles southwest of the Hawkins field, and 18 miles southeast of the Van field.

The Amerada Petroleum Corporation drilled the first well on the Sand Flat prospect on a surface structure in the winter of 1928–1929. This well was abandoned at the total depth of 5,400 feet, in the Woodbine sand. The discovery of the East Texas and Hawkins oil fields stimulated the drilling of additional Woodbine tests in the vicinity of the prospect, and this development indicated an anticlinal fold in the Upper Cretaceous in the Sand Flat area.

Exploration in the area had proved the presence of structure but had not discovered oil or gas in the Upper Cretaceous. C. L. Wickliffe and others secured leases and cash donations for drilling a deep test on the prospect and commenced their O. Hackett No. 1, S. Leeper Survey, 1 mile north of the hamlet of Sand Flat, in February, 1943. This well cored a saturated sand near the top of the

[1] Manuscript received, September 27, 1944.

[2] Skelly Oil Company.

Paluxy formation, and on a drill-stem test, from 7,281 to 7,307 feet, recovered 540 feet of heavy black oil and 630 feet of salt water. The well was drilled deeper and was abandoned at 9,852 feet, in the Rodessa section of the lower Glen Rose on July 28, 1943. Some minor showings of oil and gas were encountered in the Rodessa section.

On August 21, 1943, the Skelly Oil Company began drilling the W. C. Chisum No. 1 in the Daniel Minor Survey 3 miles south of the Wickliffe well. The Skelly location was recommended by a seismic survey, being in close agreement with the crest of the Amerada surface structure.

The Skelly well encountered the top of the Paluxy formation 285 feet higher structurally than in the Wickliffe well, and on a drill-stem test in a sand near the top of the Paluxy formation recovered 6,030 feet of 25° API gravity oil in 90 minutes. Drilling was resumed and additional showings of oil or gas were encountered in limestone at the base of the Glen Rose massive anhydrite, in sands and limestones of the Rodessa section, and in the upper and lower Pettit limestones at the base of the Glen Rose. The well was bottomed at 10,011 feet in the Travis Peak formation on December 30, 1943, and 5½-inch OD casing was cemented to bottom. On production tests the upper and lower Pettit limestones failed to respond to acid. The well was plugged back to the Rodessa section, and some 37° gravity oil was produced through perforations after acidizing; however, the well would not flow from this zone. Completion was made in the sand at the top of the Paluxy formation, through perforations from 6,972 to 7,025 feet, flowing 135 barrels of 28.2° API oil in 24 hours through a 3/16-inch choke on March 17, 1944.

Five additional wells have been drilled since the discovery, resulting in two oil wells completed in the Paluxy, two dry holes drilled to the Paluxy, and a small oil well completed in the Rodessa section of the Glen Rose. There is one drilling well and one location in the field at this time.

The structure of the Sand Flat field is an anticline, complicated with faults of minor displacement. The structural detail and area of production of the anticline can not be defined at this time.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1649-1651

DISCUSSION

CLASSIFICATION OF FAULTS, AND THRUST FAULT ON BARRANQUILLA-CARTAGENA HIGHWAY, COLOMBIA[1]

MASON L. HILL[2]
Bakersfield, California

A classification of faults[3] proposed by Stuart K. Clark has recently been applied by him to a fault exposure in South America.[4]

In a discussion[5] of the former paper, Chester R. Longwell has brought out objections to a genetic classification and has made specific criticism of the terminology used in that classification. The present writer agrees with Clark and Longwell that fault terms are often confusing and that a workable classification of faults is desirable. The writer, however, joins Longwell in disagreeing with Clark as to the usefulness of his classification and indicates herein, by a discussion of the Colombian example, how unsatisfactory this classification appears to be.

Clark's sketch of the "thrust fault"[6] shows an almost vertical fault passing downward in the road-cut to a dip of approximately 60° with an indicated upward displacement of the hanging wall. This fault is said to have been "initiated" as a "reverse diagonal shear" but according to his own classification[7] "thrust fault" is a synonymous term. The word "initiated" takes on significance, however, in the statement that ". . . tilting of the entire mass of strata is such that the upper part of the fault is now almost precisely vertical."[8] The inference is that this portion of the fault was supposed to have originally dipped approximately 45° and therefore the term used for the fault applies to a position it was imagined to have had. Clark's "vertical shear" would appear to have been more appropriate for the exposed fault but he presumably avoids this designation because mathematical calculation indicates to him that such faults occur only at great depth.[9]

Furthermore, the Colombian example of fault classification is said to pass downward into a "bedding plane shear" but in Clark's classification this term is synonymous with "horizontal fault"[10] and only by the imagined post-faulting tilt, previously referred to, can the data fit the classification.

The writer's conclusion is that Clark's use of his own fault classification is a convincing argument against that classification because a modification of observed data became necessary in order to classify the fault.

[1] Manuscript received, September 9, 1944.

[2] Richfield Oil Corporation.

[3] Stuart K. Clark, "Classification of Faults," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 9 (September, 1943), pp. 1245–65.

[4] Stuart K. Clark, "Thrust Fault on Barranquilla-Cartagena Highway, Colombia," *ibid.*, Vol. 28, No. 8 (August, 1944), p. 1219.

[5] Chester R. Longwell, "Classification of Faults," *ibid.*, Vol. 27, No. 12 (December, 1943), pp. 1633–40.

[6] Stuart K. Clark, *op. cit.* (1944).

[7] *Idem* (1943), p. 1252.

[8] *Idem* (1944).

[9] *Idem* (1943), pp. 1263–64.

[10] *Idem* (1943), p. 1255.

Probably most of us would classify the Colombian fault, on the basis of the sketch section, as an apparent "reverse fault" and if emphasis was placed on the word "apparent" the term would be quite satisfactory. If data could be obtained on the orientation of the displacement it would be possible further to describe this fault, for example, as an "oblique-slip reverse fault" with the orientation and possibly the amount of net-slip.

Perhaps a good primary classification of faults based on data commonly used as diagnostic of faulting is, with the word "apparent" implied: (1) normal, (2) reverse, and (3) lateral. When possible and desirable, other modifying descriptions are useful but the status of structural geology is certainly not sufficiently advanced for a genetic classification.

It is hoped that this discussion will stimulate, as Clark's have done, consideration of fault terminology and perhaps observation of data which are diagnostic of displacement orientation.

COMMENT[11]

STUART K. CLARK[12]
Ponca City, Oklahoma

The sketch of the fault exposed along the Barranquilla-Cartagena highway was presented simply as an interesting example of faulting cutting diagonally down through the strata in the upper part of its course and then curving to follow the bedding planes in the lower part of its course. The strata are highly tilted.

The use of the term "initiated" had reference only to the fact that in a series of alternating sandstones and shales, it must be the relatively competent sandstones rather than the incompetent shales which transmit stresses adequate to cause shearing of the sandstones. In that sense the portion of the fault which occurs along the bedding planes of the shale may be said to be consequent to that portion in which the sandstone beds are diagonally sheared. In point of time the failure could have occurred at any stage whatever of the tilting of the entire mass of strata involved.

None of the observable facts is imagined, but the interpretations placed on them may vary. I had inferred that it represented an instance of the transition from reverse diagonal shearing to bedding plane shearing. C. W. Washburne in a personal communication takes the position, based on the geometry of the situation, that it probably represents an oblique displacement.

Hill attacks the interpretation in this instance, but more particularly the system of classification which I had previously proposed. He expresses the opinion that "the status of structural geology is certainly not sufficiently advanced for a genetic classification."

It is the latter statement which moves me to respond to his discussion. I am not disposed to debate the merits of the terminology in the classification which I set up. It is quite possible that it can be improved. But I do protest against the negative conclusion that the attempt to set up any genetic classification is unwarranted.

If we can recognize even a very few genetic types, that would seem to be ample justification for starting such a classification. Disregarding differences of opinion regarding terminology and conceding that no system of classification can guarantee the correct identification of every fault encountered, in order to get at the fundamental question, would Hill go so far as to assert that the faults which I have diagrammed and described under the names "normal diagonal shears," "reverse diagonal shears," and "lateral shears" are not genetic types?

If we accept Hill's opinion that genetic classification is presently impossible, then we should logically discard all fault terminology having genetic implications.

[11] Manuscript received, September 20, 1944.

[12] Continental Oil Company.

The profession as a whole has never shown any inclination to adopt that stand; witness the profusion of terms with genetic implications in the literature: gravity fault, tension fault, thrust vault, shear, overthrust, underthrust, upthrust normal fault, ramp thrust, tear fault, et cetera.

The logical alternative is based on the attitude that intelligent speculation regarding the forces involved in geologic structures is highly desirable; that faults furnish some of the best indicators of the nature and disposition of such forces; and consequently it is desirable to attempt to set up criteria for the recognition of certain specific types of faults.

Certainly if the use of genetic terms is to be continued, there would seem to be a definite obligation to define those terms explicitly and eliminate contradictory and confusing usages, which in effect would be setting up a genetic classification of faults.

I should like to reiterate my conviction that there is a real need for such a classification and that our present knowledge of mechanics is adequate for a start on the job.

The formulation of a classification which would meet general acceptance would seem to be an appropriate task for a joint committee of the American Association of Petroleum Geologists and the Geological Society of America.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1652-1660

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

AIR PHOTOGRAPHY AND GEOLOGY, BY R. W. WILLETT

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

"Air Photography and Geology," by R. W. Willett, New Zealand Geological Survey. *New Zealand Journal of Science and Technology*, Vol. 22, No. 1B (July, 1940), pp. 21B–33B. (Published, 1941.)

The inclusion of this paper in two recent bibliographies[2] which have just reached the writer, together with current interest in its subject, prompts the following note. American petroleum geologists may also be interested to know something of what little use has been made of air photography for geological and other purposes in New Zealand.

Willett (whose paper receives an asterisk in Cobb's bibliography, indicating that it ranks among "the most important references") begins with a general introduction on the development of air photography and its importance and usefulness in many branches of science and technology. He indicates his preference for the terms "air photography," "air survey," "air geology," et cetera, rather than "aerial. . . ," in order to avoid confusion with "areal" as applied to geology and, further, because the use of "aerial" reminds one "sometimes of Milton [?—Shakespeare—B. W. C.] and sometimes of broadcasting"—quoting from H. S. L. Winterbotham (*Trans. Inst. Min. and Met.*, Vol. 42 (1932), p. 158).

There then follows an account of the use made of air photographs in the work of the New Zealand Geological Survey, beginning with a mosaic made in 1930 during the course of work in the Te Kuiti Subdivision (North Island).[3] Air photographs were subsequently used in several other areas, principally to check topographic details mapped by the ground survey, but also to assist in the determination of geological boundaries and the location of faults. The most extensive use of air photography was made in the Glenorchy Subdivision (South Island), where, from 1937 to 1939, 300 square miles of extremely rugged country were mapped under the direction of Willett himself.[4]

The photographs were taken from an altitude of 11,000 feet, but even this was not high enough to overcome the distortion and gaps that arose from the high relief (up to 7,000 feet) of the area, which has an average slope of one-in-one. From the photographs detailed topographic maps contoured at 1,000-foot intervals were prepared, and on this base the geological field work, together with geological information gained from a stereoscopic study of the prints, was plotted. Ground control was obtained by fixing points, determinable in the photographs, by theodolite observations, and more especially by photo-

[1] P.O. Box 10, Auckland, New Zealand. Manuscript received, September 12, 1944.

[2] Marie Siegrist and Elizabeth T. Platt, *Bibliography of Military Geology and Geography. First Supplement*, Geol. Soc. America (New York, January, 1943). 11 pp.
Genevieve C. Cobb, "Bibliography on the Interpretation of Aerial Photographs and Recent Bibliographies on Aerial Photography and Related Subjects," *Bull. Geol. Soc. America*, Vol. 54, No. 8 (August, 1943), pp. 1195–1210.

[3] H. T. Ferrar, "Geology and Soils of Parts of the King-country, Te Kuiti Subdivision," *New Zealand Geol. Survey 24th Ann. Rept.* (1930), pp. 4–6.

[4] R. W. Willett, "Glenorchy Subdivision," *New Zealand Geol. Survey 33rd Ann. Rept.* (1939), pp. 7–9.

graphic panoramas taken from suitable points throughout the area. This district was the first to be completely mapped from air photographs by the New Zealand Geological Survey.

The author concludes this section of his paper by stating that

> although the actual area covered by air photography in New Zealand for the Geological Survey is small, the usefulness of air photography has been amply demonstrated. . . . At present really first-class topographic maps that can be used as a base for geological work are practically non-existent in New Zealand; . . . in some parts of the country . . . about half of the geologist's time is occupied in carrying out topographical work.

The writer of this review can, from personal experience as a field geologist for a company engaged in petroleum exploration in New Zealand, fully endorse Willet's prediction "that the future must result in further geological work being carried out with the aid of air photography."

As far as the writer is aware no petroleum company has yet made any use of air photographs in New Zealand, but it is obvious that much time would be saved, and greater accuracy attained, if an air survey were made of possible oil-producing districts—such, for example, as the forested country of central and northern Taranaki (west coast of North Island)—before a ground geological survey were undertaken. The topographical information obtained would alone repay the cost of such a survey (and, further, the expenses might be shared by various Government departments), while it is probable that geological features would be revealed on the photographs to an experienced interpreter which might be missed entirely by a ground survey or only discovered after much arduous work. These remarks apply, of course, with even greater force, to countries like New Guinea, where progress on the ground is slow and difficult and distances and areas are many times those of New Zealand. While the writer was in New Guinea in 1937 and 1938 air surveys were begun by oil exploration companies, but their results are not available to him.

The next section of Willett's paper describes the interpretation of geological features from air photographs, in terms familiar by now to most geologists, and citing from his own experience in the survey of the Glenorchy Subdivision. One of the most interesting of his discoveries was the offsetting of a lode fissure by minor parallel faults and the tracing of the continuation of the lode itself, which he has described in a separate paper.[5]

One of the most valuable parts of the paper under review is a section on the costs of air surveys. Willett here gathers from the literature at his disposal some figures on the cost per square mile of air surveys in various countries, which may be summarized as follows.

United States.—Board of Surveys and Maps, proposal to map some 2,200,000 square miles, final topographic map to be of scale 1:62,000, with 20-foot contours, estimate $54 a square mile (£10.5 per square mile).

Northern Rhodesia.—65,000 square miles mapped, scale 1:250,000, cost £1 per square mile.

South America.—400,000 square miles mapped, scale 1:50,000, 25-meter contours, cost £3.8 per square mile. (Cost of similar topographic map by normal ground methods estimated at about £40 per square mile.)

Norway.—Cost of air survey 40 per cent less that that of other methods.

Australia.—Aerial, geological, and geophysical survey of Northern Australia by Commonwealth Government (1934–1937), cost £1.8 per square mile.

New Zealand.—Glenorchy Subdivision, 300 square miles, total cost of photography, reduction of photographs, and ground control, £2.1 per square mile. Topographic map produced on scale of 15 chains to the inch (1:11,880) with 1,000-foot contours. (Minimum cost by normal ground survey about £2.7 per square mile.)

The author points out, of course, that air-photographic survey compares more than

[5] R. W. Willett, "The Invincible Lode," *New Zealand Jour. Sci. and Tech.*, Vol. 21 (1940), pp. 273B–280B.

favorably with normal methods in detail, accuracy, quality, and the speed of production of the final map. In addition, in the case of the Glenorchy Subdivision, the amount of geological information obtained from the air photographs, with a corresponding reduction in the amount of geological field work, must be set against the initial cost of the air survey. Further, the air photographs made it possible to map accurately the geology of the high, precipitous and inaccessible parts of the Richardson Mountains which must otherwise have remained unknown. The final picture of the geology of the Glenorchy area is stated to be different from (and more accurate than) that which would have resulted from ground-survey methods alone. Detailed fault maps would have been impossible without the aid of air photographs.

Air photographs have been used by other Government departments in New Zealand, and for the following information on the extent to which they have been employed by the Public Works Department in the province of Canterbury (east coast of South Island), the present writer is indebted to his brother, N. W. Collins, of the engineering staff of this department.

A large number of obliques were used to construct a large-scale relief model of the province for the New Zealand Centennial Exhibition, held in Wellington in 1940. This model is now housed in the Canterbury Museum, Christchurch. The mountains, trigonometrical stations, and other relief features were identified on the photographs and their detail shapes obtained. Other features shown on the model, obtained largely from the photographs, included details of land utilization, crops, plantations, layout of towns, *et cetera*, as well as the location and extent of snowfields and glaciers.

In South Canterbury the plains and foothills of the Southern Alps from the Rakaia River to the south of the town of Timaru have been covered fairly completely by some 5,000 verticals from 9,000 feet and about 100 obliques from about 10,000 feet. The verticals were used mainly to give a cheap topographic survey for many purposes. For the Downs Water Supply Scheme the photographs supplied details of each farm and showed the topography for the layout of pipe lines. Similar information was supplied for the Levels Plain, Ashburton-Lyndhurst and Mayfield-Hinds Irrigation Schemes. Much general information about the river was obtained for the Ashburton River Control Scheme.

To show up the topography better, a portable stereoscope has been used in the Christchurch District Office of the Department, but the Head Office in Wellington has equipment for taking accurate contours. The Lands and Survey Department has also used the vertical photographs extensively. In general, air photographs are not used by the Public Works Department so much for preparing schemes as for getting accurate and comprehensive topographical information to supplement ground surveys.

This brief account of what has been done in one province may serve to indicate that New Zealand, in common with other countries, had, even before the war, come to appreciate the value of air surveys, and it is certain that in the future this method will be used much more extensively. One field, of importance in New Zealand, is that of accelerated soil erosion and flood control.

In Australia also the aeroplane has been enlisted in the service of geology. Papers by Australian geologists listed in Cobb's bibliography include one by C. T. Madigan on an aerial reconnaissance of part of Central Australia, and four by W. G. Woolnough, who, in 1941, was elected an honorary member of the American Association of Petroleum Geologists. The most recent of Woolnough's papers[6] is a general one, pointing out the advantages to a geologist of a bird's-eye view of the ground on which he is working. One interesting opinion worth quoting is:

[6] W. G. Woolnough, "The Aeroplane in the Service of Geology," *Jour. and Proc. Roy. Soc. New South Wales*, Vol. 70, Pt. 1 (January, 1937), pp. 39–62; 2 pls., 2 figs.

The writer's [Woolnough's] experience is that it takes something like one hundred hours of flying before one can sufficiently dissociate himself from the act of flying to concentrate all his faculties on systematic scientific observation. By this time also the unfamiliarity of the panorama has been overcome, and a new standard of topographic expression has been evolved.

In regard to air photographs Woolnough states:

I hope to live long enough to see the study of interpretation of aerial photographs, based on personal observation from the air, introduced as an essential feature of advanced geological training in our teaching institutions.

In conclusion he emphasizes two important facts in relation to the new methods of geologic mapping:

Firstly, they supplement, and do not supplant, the methods of Clarke [a pioneer Australian geologist who mainly by means of horse transport explored a great part of the colony of New South Wales many years ago—B.W.C.] and his contemporaries; secondly, the new methods require just as much study and mental and physical discipline as does the employment of any other branch of the science of geology.

PROGRESS REPORTS ON GEOLOGY OF ALASKA HIGHWAY[1]

J. V. HOWELL[2]
Tulsa, Oklahoma

During the past two summers geologists of the Geological Survey of Canada have been studying the area adjacent to the Alaska Highway, hitherto inaccessible. Progress reports are now being issued in the form of mimeographed text and blue-line maps. The following relate to the Highway and its immediate vicinity.

Paper 44–30, "Geology Adjacent to the Alaska Highway between Fort St. John and Fort Nelson, British Columbia," by C. O. Hage. (Report and map.)

The report covers the area adjacent to the Highway for a distance of 257 miles northwestward from Fort St. John, on the Peace River. Rocks of Mississippian, Triassic, Jurassic, and Cretaceous ages are described, and five anticlinal folds, forming a belt along the foothills, are discussed.

The presence of Lower Mississippian (Kinderhook) beds has not been noted previously in this area, although reported farther north on the Liard River.

Paper 44–28, "Geological Investigations along the Alaska Highway from Fort Nelson, British Columbia, to Watson Lake, Yukon," by M. Y. Williams. (Report and map.)

The area described in this report has been almost unknown previously, except for brief notes by Dawson and McConnell (1887) and Williams (1922), who made hurried trips through the area. The present paper covers a belt 370 miles in length and extends from the plains area on the east, well into the Rocky Mountains on the west.

Rocks of ages ranging from pre-Cambrian to Upper Cretaceous are described, of which an extensive series of Mississippian beds (Burlington, Keokuk, and possibly Chester) are new, and have not as yet been named. The presence of relatively open folds underlain by thick sections of marine shales and limestones suggests that the general area may have promise.

[1] Manuscript received, September 8, 1944.

[2] 1506 Philtower Building.

Paper 44–16, "Geological Reconnaissance along Fort Nelson, Liard, and Beaver Rivers, Northeastern British Columbia and Southern Yukon," by E. D. Kindle. (Report and map.)

This report is of especial interest inasmuch as a thickness of approximately 1,750 feet of beds, identified by their fauna as Pennsylvanian and Permian in age, is described. Beds of Lower Triassic age reach a thickness of 1,900 feet and approximately 4,700 feet of Lower Cretaceous and 1,500 feet of Upper Cretaceous make up a most interesting assemblage of largely marine beds overlying the marine Permian and Pennsylvanian.

Many relatively open folds are recognized and described.

Paper 44–25, "Geological Reconnaissance along the Alaska Highway between Watson Lake and Teslin River, Yukon and British Columbia," by C. S. Lord. (Report and map.)

This area lies within the Rocky Mountains, and the rocks are chiefly igneous and metamorphic. Oil possibilities appear to be negligible.

Paper 44–19, "Dunlevy-Portage Mountain Map-area, British Columbia, by H. H. Beach and J. Spivak. (Report and map.)

This area lies immediately west of the Highway, along the Peace River, and includes a very complete and accessible section of Triassic, Jurassic and Lower Cretaceous beds (almost 12,000 feet), In addition some 415 feet of fossiliferous Permian beds are described, this being the first recorded occurrence in Canada.

The following reports relate to the Peace River area adjacent to that river and accessible from the Highway.

Paper 44–2, "Geology and Oil Prospects of Lone Mountain Area, British Columbia," by F. H. McLearn and J. F. Henderson. (Report and map.)

Paper 44–7, "Geology and Coal Deposits of Hasler Creek Area, British Columbia," by J. Spivak. (Report and map.)

Paper 44–13, "Stratigraphy and Structure in Mount Hulcross-Commotion Creek Map-Area, British Columbia," by R. T. D. Wickenden and G. Shaw. (Report and map.)

Paper 44–15, "Some Coal Deposits of the Peace River Foothills, British Columbia," by F. H. McLearn and E. J. W. Irish. (Report only.)

Paper 44–17, "Revision of the Lower Cretaceous of the Western Interior of Canada," by F. H. McLearn.

Paper 44–31, "Preliminary Map of Ponce Coupé-Peace River, Alberta and British Columbia, by C. H. Crickmay. (Map and brief text.)

This paper includes a brief description of gas wells drilled recently on Ponce Coupé Creek, just south of Peace River.

"Mineral Possibilities of Areas Adjacent to the Alaska Highway. Part I, Yukon Section," compilation by L. O. Thomas. *Canadian Inst. Min. Met. Trans.*, Vol. 46 (1943), pp. 375–401.

This is an excellent digest of the information available relating to Minerals in the area traversed by the northern section of the Highway. It also includes, in an appendix, the regulations covering use of the Highway, and has a complete bibliography.

The Southern Half of the Alaska Highway, and Its Mammals, by A. L. Rand.

In addition to information of the animal life, the report gives rather full descriptions of the geography, and includes, on pages 24 to 29, an interesting description of the so-called "Tropical Valley" (which is described also in *Paper 44–28* in foregoing list), frequently mentioned in popular magazine stories.

HISTORICAL GEOLOGY, BY RUSSELL C. HUSSEY

REVIEW BY W. A. VER WIEBE[1]
Wichita, Kansas

Historical Geology, by Russell C. Hussey, professor of geology at the University of Michigan. McGraw-Hill Book Company, New York (1944). 473 pp. including 344 figs. with preface, table of contents, and index. Price, $3.50.

Many books have been written on the subject of historical geology, some long, some short, some thoroughly technical, and some relatively non-technical. Nearly all are intended to interest the beginner in college who "elects" to take a second course in geology. Most of these books written in the past have been too comprehensive both in the matter of data presented and in the manner of presentation. As a result the beginner is left floundering in a sea of confusion and the spark of interest aroused by the teacher is suffocated by the dullness of a textbook he does not understand.

Perhaps it is the spirit of the times, when streamlining is the watchword, which has prompted Dr. Hussey to depart from the conservative methods of his predecessors. He has stepped down from the dignified pedestal of the professor to address his students on their own ground level. He starts them at the beginning with simple concepts and then proceeds in a methodical, logical, orderly sequence to build up these concepts to the levels which will allow them to comprehend the strange events of super-ancient history. Thus the student constantly feels the guiding hand of a travel companion at his side while he pages his way through the book.

Dr. Hussey begins by telling his reader about fossils—what they are—how they were formed—how they were preserved and in what places they may be found. Many of the terms such as permineralization, mold, carbon films, *et cetera* are explained in a thoroughly understandable manner, and the reader really feels that he knows fossils when he finishes the first chapter. The reconstruction of fossils is always a subject of some mystery to beginners, and this also is explained in a most lucid fashion.

In Chaper III the somewhat contentious subject of evolution is taken up. Here again Dr. Hussey comes right down to the level of the knowledge and experience of the layman and explains in easily understandable terms the reasons why scientists incline to a belief in evolution of life forms.

The origin of the earth and its earliest history is touched upon rather lightly as the extremely hypothetical nature of the data demand. Nevertheless, the reader is left with certain definite fundamental ideas. Other fundamentals, such as the geological time scale and the reasons for the subdivisions of geological time, are next taken up. The difficult concept of correlation is treated very admirably and convincingly. Similarly, the interrelation between physical events and the progressive march of life-forms is simply and accurately revealed.

The complicated history of Archeozoic time is greatly simplified so as not to confuse the reader at the outset. The number of formation names is reduced to a minimum and the lithologic descriptions are brief and pointed. The events of Proterozoic time are somewhat more fully presented and the story is made interesting by abundant reference to well known places in the United States. The emphasis is on the economic products and the history of mountain-making in both the Proterozoic and the Archeozoic.

In the discussion of the Paleozoic era, each period is taken up separately and the important physical events described briefly as they relate to North America. Sedimentation, climate, mountain-building, and life forms are each treated with equal attention. A simple table showing the principal formations or groups is presented with each period except the

[1] Professor of geology at the University of Wichita. Manuscript received, October 4, 1944.

Cambrian. A good map of North America shows the distribution of seas and lands as well as the present outcrops of each system. In connection with the story of the life-forms emphasis is placed upon the characteristic types of life and the new invasions of the higher forms. Good illustrations make this part of each presentation especially effective. Under the heading of Devonian a very interesting set of data is presented to show the evolution of lungs and also the evolution of limbs. The discussion of the Permian is particularly noteworthy because of the inclusion of much recently published information.

The Mesozoic periods are treated in similar manner except that here the interesting story of the great reptiles is considerably expanded. The physical events along the Pacific are given equal space with those of the eastern and central parts of the continent. Considering the deep interest which students usually manifest for information on Mesozoic dinosaurs and their cousins, this portion of the book shows a very great advance over anything ever attempted previously. The information is fresh and written in an attractive style. Excellently chosen illustrations reinforce the descriptive passages.

In connection with the Cenozoic era the term Quaternary is dropped and all epochs from the Eocene to the Recent are treated as subdivisions of the Tertiary. Here the history of mountain-building is particularly complete and refreshingly up-to-date. The Pleistocene is treated in a separate chapter and includes a rather full discussion of the history of the Great Lakes, which is helpful in persuading students to believe that great changes are possible and have actually occurred in the past. The life forms of the Cenozoic are treated with considerable completeness and many new findings based on recent researches are here presented for the first time. The evolutionary development of the horse family and of the elephant family is portrayed in a convincing manner. Chapter 21 is devoted to the Primates. Inasmuch as students, being human beings, are always more interested in the history of the human family than in any other phase of the subject, Dr. Hussey has wisely chosen to make this chapter as complete and interesting as possible. Not only are the actual human ancestors and their near-human relatives described fully, but also the various tribes of Cro-Magnon man are discussed in detail. In the appendix, called "The Study of Fossils," just enough detail is presented to enable the student to enjoy the previous pages of the book without becoming too involved in paleontology.

Every member of the American Association of Petroleum Geologists, no matter how old or how "experienced" he may be, will want to have the pleasure of perusing this delightful portrayal of an old old story. Although written with the definite objective of serving as a textbook to college freshmen, the book contains enough new material to justify inspection. Once the reader gets started with his inspection, he will find that the fascinating style of the author will hold him until he has finished the last page.

RECENT PUBLICATIONS

AUSTRALIA

"The Stratigraphy of the Tertiary Marine Rocks in Gippsland, Victoria," by Irene Crespin. *Commonwealth of Australia Mineral Resources Survey Bull. 9*, Palaeontological Ser. 4 (Canberra, August 10, 1943). 101 pp., 8 figs., 5 tables, distribution chart of fossils. Mimeographed. Paper covers. 8.25 × 13 inches.

ARKANSAS

"Geologic Map and Structure Sections of the Batesville District, Independence County, Arkansas," by Mackenzie Gordon, Jr., and Douglas M. Kinney. *U. S. Geol. Survey Prelim. Map 12*, Oil and Gas Inves. Ser. (1944). May be bought from Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.40.

CALIFORNIA

* "Prospects Favorable for Deeper California Production," by Albert Gregersen and Frank S. Parker. *Oil Weekly*, Vol. 115, No. 4 (Houston, September 25, 1944), pp. 34–46; 5 maps, 5 charts.

* "Prospects for Deeper Zone Production in California," by Albert Gregersen and Frank S. Parker. *California Oil World*, Vol. 37, No. 18 (Los Angeles, September, 1944), pp. 12–21; 5 maps, 5 charts.

* "Navy's Elk Hills Reserve Tapped to Meet Critical Oil Shortage," by E. S. Bunch. *Oil Weekly*, Vol. 115, No. 5 (Houston, October 2, 1944), pp. 36–46; 6 illus.

* "Geologic Significance of a Coarse Marine Sediment from near Santa Catalina Island, California," by Thomas Clements and Stephen W. Dana. *Jour. Geol.*, Vol. 52, No. 5 (Chicago, September, 1944), pp. 351–54; 1 fig.

COLOMBIA

*"Geology of the Barco Concession, Republic of Colombia, South America," by Frank B. Notestein, Carl W. Hubman, and James W. Bowler. *Bull. Geol. Soc. America*, Vol. 55, No. 10 (New York, October, 1944), pp. 1165–1216; 6 pls., 12 figs. Separates of this article, of special interest to petroleum geologists, may be ordered from A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma. Price, $0.50, postpaid.

COLORADO

* "Reconsideration of the Morrison Formation in the Type Area, Jefferson County, Colorado," by W. A. Waldschmidt and L. W. LeRoy. *Bull. Geol. Soc. America*, Vol. 55, No. 9 (New York, September, 1944), pp. 1097–1114; 4 pls., 3 figs.

GENERAL

* "Analysis of Decline Curves," by J. A. Arps. *Petroleum Technology*, Vol. 7, No. 5 (New York, September, 1944). 20 pp., 7 figs., 5 tables. *A. I. M. E. Tech. Pub. 1758.*

* "Applications of the Electric Pilot to Well Completions, Acidizing, and Production Problems in the Permian Basin," by P. J. Lehnhard and C. J. Cecil. *Ibid.* 10 pp., 9 figs. *A. I.M. E. Tech. Pub. 1759.*

* "Petroleum Development and Technology, 1944." *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 155 (1944). 581 pp. Published by the Institute, 29 West 39th Street, New York, N.Y. Price, $5.00, net.

* "Geochemistry as Aid to Successful Exploration," by John W. Merritt. *Oil Weekly*, Vol. 115, No. 6 (Houston, October 9, 1944), pp. 35–38; 4 figs.

* "Team of Geology and Drill Has Responsibility of Solving Industry's Oil-Finding Problem," by Ira H. Cram. *Independent Monthly*, Vol. 15, No. 6 (Tulsa, October, 1944), pp. 46–48.

The Mines Magazine, 9th Annual Petroleum Number (Denver, Colorado, September, 1944). 116 pp., 6 maps, 21 tables, 7 drawings. Contains the following articles.

"The Future of Oil," by Eugene Holman
"Utilization of Cumulative Production Data," by James Ogden Ball
"Notes on Geology and Oil Development—Middle East," by A. W. Weeks
"Progress in Petroleum Exploration," by F. M. Van Tuyl
"Oil Search in the Eastern Gulf Region," by Joseph A. Kornfeld
"International Struggle for Petroleum," by Meherwan Cavasji Irani
"Interstate Oil Compact Commission—An Emblem of Democracy," by T. C. Knoop, Jr.

"Oil and Gas Prospects in the Rockies," by Thomas S. Harrison

"Oil on the Water," by E. G. Maddock

"Characteristics and Significance of Oil Field Waters of the Rocky Mountain Region," by James G. Crawford

"Detection of Mechanical Troubles in Diesel Engines by Oil Analysis," by L. C. Atchison

"Colorado Oil Sales," by Robert A. Baxter

"Geophysical News and Reviews," by Geophysics Department, Colorado School of Mines

May be ordered from Mines Magazine, 734 Cooper Building, Denver (2), Colorado. Price, $1.00.

MICHIGAN

"Geology and Oil and Gas Possibilities of South-Central Michigan." *U. S. Geol. Survey Prelim. Map 11*, Oil and Gas Inves. Ser. (1944). May be bought from: (1) Director, U. S. Geol. Survey, Washington 25, D. C.; (2) Geol. Survey Division, Lansing 13, Michigan. Price, $0.25.

OKLAHOMA

"Geological Map of the Dougherty Asphalt Area, Murray County, Oklahoma," by Joseph M. Gorman and George M. Flint, Jr. *U. S. Geol. Survey Prelim. Map 15*, Oil and Gas Inves. Ser. (1944). May be bought from the Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.25.

TENNESSEE

* "Ordovician Bentonites in Tennessee and Adjacent States," by Portland P. Fox and Leland F. Grant. *Jour. Geol.*, Vol. 52, No. 5 (Chicago, September, 1944), pp. 319–32; 5 figs., 2 tables.

TEXAS

* "Oil Shale of Central Texas," by F. B. Plummer and Bruce Grant. *Oil and Gas Jour.*, Vol. 43, No. 22 (Tulsa, October 7, 1944), pp. 66–70; 1 map.

WYOMING

"Geologic and Structure Contour Map of the Maverick Springs Area, Fremont County, Wyoming," by D. A. Andrews. *U. S. Geol. Survey Prelim. Map 13*, Oil and Gas Inves. Ser. (1944). May be bought from the Director, U. S. Geol. Survey, Washington 25, D. C. Price, $0.40.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1661-1665

THE ASSOCIATION ROUND TABLE

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

IRA H. CRAM, *chairman*, Pure Oil Company, Chicago, Illinois
ROBERT E. RETTGER, *secretary*, Sun Oil Company, Dallas, Texas
A. RODGER DENISON, Amerada Petroleum Corporation, Tulsa, Oklahoma
WARREN B. WEEKS, Phillips Petroleum Company, Bartlesville, Oklahoma
GAYLE SCOTT, Texas Christian University, Fort Worth, Texas

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL: M. G. CHENEY (1946)

REPRESENTATIVES ON COMMISSION ON CLASSIFICATION AND NOMENCLATURE OF ROCK UNITS

JOHN G. BARTRAM (1945) C. W. TOMLINSON (1946) M. G. CHENEY (1947)

FINANCE COMMITTEE

JOSEPH E. POGUE (1945) CHARLES E. YAGER (1946) FRANK R. CLARK (1947)

TRUSTEES OF REVOLVING PUBLICATION FUND

W. B. WILSON (1945) WALLACE E. PRATT (1946) WILLIAM D. KLEINPELL (1947)

TRUSTEES OF RESEARCH FUND

W. R. BERGER (1945) CLARENCE L. MOODY (1946) E. O. MARKHAM (1947)

BUSINESS COMMITTEE

GEORGE S. BUCHANAN (1946), *chairman*, 2302 Esperson Building, Houston, Texas

J. D. AIMER (1945)
GORDON I. ATWATER (1945)
ROBERT L. BATES (1945)
RICHARD W. CAMP (1945)
T. C. CASH (1945)
R. CLARE COFFIN (1945)
EDWIN G. COLE (1945)
IRA H. CRAM (1946)
CARLE H. DANE (1946)
DONALD M. DAVIS (1946)
A. R. DENISON (1945)
BARNEY FISHER (1946)
GUY B. GIERHART (1945)
REX P. GRANT (1945)
S. G. GRAY (1945)
DARSIE A. GREEN (1945)
M. GORDON GULLEY (1945)
MASON L. HILL (1945)
JOHN M. HILLS (1946)
DONALD D. HUGHES (1945)
WILLIAM C. IMBT (1945)
JAMES C. KIMBLE (1945)
CHARLES S. LAVINGTON (1945)
D. E. LOUNSBERY (1946)
F. H. MCGUIGAN (1945)
TOM MCGLOTHLIN (1945)
W. B. MOORE (1945)
PHILIP E. NOLAN (1945)
ELISHA A. PASCHAL (1946)
EDWIN L. PORCH (1946)
ROBERT E. RETTGER (1945)
GAYLE SCOTT (1945)
J. G. SPRATT (1945)
HENRYK B. STENZEL (1945)
EARL M. STILLEY (1946)
EUGENE H. VALLAT (1946)
LUCIAN H. WALKER (1945)
LEWIS G. WEEKS (1945)
WARREN B. WEEKS (1945)
ROBERT T. WHITE (1946)
C. E. YAGER (1945)

COMMITTEE FOR PUBLICATION

J. V. HOWELL (1945), *chairman*, 1506 Philtower Building, Tulsa, Oklahoma
C. E. DOBBIN (1946), *vice-chairman*, 425 Denham Building, Denver, Colorado

1945	1946	1947
JOSEPH L. BORDEN	GORDON I. ATWATER	J. E. BILLINGSLEY
KENDALL E. BORN	JAMES R. DORRANCE	J. I. DANIELS
R. L. CLIFTON	FENTON H. FINN	HOLLIS D. HEDBERG
CLIFTON S. CORBETT	EARL P. HINDES	LEE C. LAMAR
LYNN K. LEE	GEORGE S. HUME	STUART MOSSOM
E. RUSSELL LLOYD	GEORGE D. LINDBERG	E. A. PASCHAL
H. E. MINOR	A. C. WRIGHT	K. K. SPOONER
		T. E. WEIRICH

RESEARCH COMMITTEE

M. G. CHENEY (1945), *chairman*, Box 846, Coleman, Texas

1945	1946	1947
N. WOOD BASS	C. I. ALEXANDER	E. R. ATWILL
RONALD K. DEFORD	ALFRED H. BELL	ROLAND F. BEERS
M. G. EDWARDS	WALTER R. BERGER	G. C. GESTER
WINTHROP P. HAYNES	PAUL E. FITZGERALD	STUART E. BUCKLEY
PHILIP B. KING	W. C. KRUMBEIN	ROBERT N. KOLM
A. I. LEVORSEN	RALPH A. LIDDLE	S. W. LOWMAN
TOM MCGLOTHLIN	W. H. TWENHOFEL	D. PERRY OLCOTT
	F. M. VAN TUYL	JOSEPH A. SHARPE

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

JOHN G. BARTRAM (1945), *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

1945	1946	1947
ROBERT I. DICKEY	GORDON I. ATWATER	STUART K. CLARK
HUGH D. MISER	DARSIE A. GREEN	ROY T. HAZZARD
RAYMOND C. MOORE	RALPH W. IMLAY	W. J. HILSEWECK
NORMAN L. THOMAS	HORACE D. THOMAS	WAYNE V. JONES
	C. W. TOMLINSON	W. ARMSTRONG PRICE

SUB-COMMITTEE ON POST-CRETACEOUS

W. ARMSTRONG PRICE (1947), *chairman*, Box 1860, Corpus Christi, Texas

HENRY V. HOWE	B. W. BLANPIED	GORDON I. ATWATER
WAYNE V. JONES	F. STEARNS MACNEIL	THOMAS L. BAILEY
TOM MCGLOTHLIN	E. A. MURCHISON, JR.	MARCUS A. HANNA
		PHILIP S. MOREY

SUB-COMMITTEE ON MESOZOIC

RALPH W. IMLAY (1946), *chairman*, U. S. Geological Survey, Washington, D. C.

C. I. ALEXANDER	PHILIP S. MOREY	G. D. THOMAS
C. E. DOBBIN	HENRY J. MORGAN	NORMAN L. THOMAS
L. R. MCFARLAND	GAYLE SCOTT	

COMMITTEE ON APPLICATIONS OF GEOLOGY

PAUL WEAVER (1947), *chairman*, Gulf Oil Corporation, Houston, Texas

1945	1946	1947
ROBERT I. DICKEY	R. M. BARNES	LEO R. FORTIER
CECIL H. GREEN	J. BRIAN EBY	THOMAS A. HENDRICKS
M. M. LEIGHTON	H. S. MCQUEEN	KENNETH K. LANDES
R. B. RUTLEDGE	R. A. STEINMAYER	

MEDAL AWARD COMMITTEE

A. RODGER DENISON, *chairman* (1945), Amerada Petroleum Corporation, Tulsa, Oklahoma
DONALD D. HUGHES, *ex officio*, president of S.E.P.M.
WILLIAM M. RUST, JR., *ex officio*, president of S.E.G.

1945	1946	1947
G. CLARK GESTER	FRANK R. CLARK	H. B. FUQUA
DARSIE A. GREEN	RAYMOND F. BAKER	THORNTON DAVIS
WALLACE C. THOMPSON	JAMES A. MACDONELL	HUGH D. MISER

NATIONAL SERVICE COMMITTEE

KENNETH C. HEALD, *chairman*, The Gulf Companies, Box 1166, Pittsburgh, Pennsylvania

FRITZ L. AURIN	JOHN O. GALLOWAY	EDWARD A. KOESTER
A. E. BRAINERD	M. GORDON GUILEY	MORRIS M. LEIGHTON
GEORGE M. CUNNINGHAM	W. DOW HAMM	PHIL F. MARTYN
THORNTON DAVIS	WINTHROP P. HAYNES	DEAN A. MCGEE
RONALD K. DEFORD	W. B. HEROY	CLARENCE L. MOODY
A. RODGER DENISON	HAROLD W. HOOTS	

DISTINGUISHED LECTURE COMMITTEE

JOHN L. FERGUSON, *chairman*, Amerada Petroleum Corporation, Tulsa, Oklahoma

JOHN W. INKSTER W. J. HILSEWECK FRED H. MOORE GROVER MURRAY, JR.

COMMITTEE ON SOUTH AMERICAN GEOLOGY

A. I. LEVORSEN, *chairman*, 221 Woodward Boulevard, Tulsa, Oklahoma

COMMITTEE ON CODE OF ETHICS

C. W. TOMLINSON, *chairman*, 509 Simpson Building, Ardmore, Oklahoma

RAYMOND F. BAKER ORVAL L. BRACE HAROLD W. HOOTS T. S. HARRISON

COMMITTEE ON METHOD OF ELECTION OF OFFICERS

JOHN G. BARTRAM, *chairman*, Stanolind Oil and Gas Company, Tulsa, Oklahoma

RONALD K. DEFORD JOHN S. IVY C. L. MOODY
W. DOW HAMM HUGH D. MISER EARL B. NOBLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Bryan D. Beck, Jr., Beaumont, Tex.
Donald D. Braugh, Harold Denton, C. B. Claypool

Wayne Moore Felts, Boulder, Colo.
T. E. Weirich, E. I. Thompson, D. E. Lounsbery

Louis Samuel Gardner, Washington, D. C.
Arthur A. Baker, Hugh D. Miser, William W. Rubey

Robert Jay Garrett, Graham, Tex.
M. G. Cheney, D. A. McGee, Harold D. Jenkins

George Henry Hansen, Provo, Utah
Kenneth A. Gorton, L. Murray Neumann, J. Stewart Williams

Dan Edward Holland, Midland, Tex.
B. E. Thompson, H. M. Bayer, W. J. Hilseweck

William Elliott Humphrey, Caracas, Venezuela, S. A.
Joseph M. Patterson, Ralph W. Imlay, Lewis B. Kellum

William Russell Johnson, Midland, Tex.
Marion H. Funk, S. W. Brock, Jr., Eugene C. Reed

Theodore Sidney Jones, Midland, Tex.
Morgan J. Davis, V. C. Maley, E. Russell Lloyd

Robert Louis Kretz, Brookhaven, Miss.
Robert Dyk, L. I. Brown, G. W. Gulmon

James Raymond Mayeaux, Midland, Tex.
Robert I. Dickey, Charles D. Vertrees, C. E. Bradford
Paul Hugh Nelson, Jal, N. Mex.
W. K. Davis, Wilton E. Scott, R. L. Boss

FOR ASSOCIATE MEMBERSHIP

Oren Cecil Baptist, Bogota, Colombia, S. A.
Philip Andrews, James A. Tong, B. O. Winkler
Edward Watson Beedle, Jr., Tulsa, Okla.
W. B. Wilson, P. H. Reisher, W. E. Bernard
Paul Otamendi Blanco, San Tome Terminal, Venezuela, S. A.
H. D. Hedberg, P. E. Nolan, Louis Sass
Luis Camminati-Cortes, Austin, Tex.
Hal P. Bybee, Fred M. Bullard, F. L. Whitney
Robert Louis Frossard, Tulsa, Okla.
G. H. Westby, A. J. Barthelmes, Stanley W. Wilcox
Leo Carroll Gravis, Harlingen, Tex.
P. B. Leavenworth, A. E. Getzendaner, W. B. Milton, Jr.
Charles Freeman Maginnis, San Francisco, Calif.
R. A. Steinmayer, Alfred R. Loeblich, Helen Tappan Loeblich
John Oscar Nigra, North Hollywood, Calif.
Bruce L. Clark, William L. Horner, Dwight H. Fortine
William Thomas O'Gara, Midland, Tex.
Leo R. Newfarmer, R. C. Spivey, R. H. Schweers
Georges Pardo (Soublette), Barcelona, Venezuela, S. A.
Hollis D. Hedberg, Louis Sass, P. E. Nolan
Eduardo Pflucker-Cabieses, Austin, Tex.
Hal P. Bybee, H. H. Power, F. L. Whitney
Jack Burnside Ryan, New York, N. Y.
V. E. Monnett, Charles E. Decker, C. G. Lalicker
Gilbert Karstens Sievers, Wichita, Kan.
W. A. Ver Wiebe, Edward A. Koester, T. N. Roberts

FOR TRANSFER TO ACTIVE MEMBERSHIP

Alberto R. V. Arellano, Mexico, D. F., Mexico
Manuel Alvarez, Jr., William G. Kane, Ezequiel Ordonez
Donald Boyd Eicher, New York, N. Y.
H. W. Haight, William E. Wallis, O. A. Seager
Richard S. Hicklin, Rawlins, Wyo.
H. F. Moses, M. W. Fuller, E. O. Markham
Dan F. Kralis, Jr., Craig, Colo.
W. C. Imbt, Ervin L. Selk, Kenneth J. Reid
Robert Fredrick Meyer, Lander, Wyo.
Edward A. Koester, Virgil B. Cole, Harold O. Smedley
Fred M. Nelson, Newgulf, Tex.
Albert G. Wolf, Paul Weaver, Donald M. Davis
Russell Ray Simonson, Los Angeles, Calif.
Glen B. Gariepy, R. W. Clark, Herschel L. Driver

30TH ANNUAL MEETING, TULSA, MARCH 20–22, 1945

The executive committee has accepted the invitation of the Tulsa Geological Society to hold the 30th annual meeting of the Association at Tulsa. The days selected are Tuesday, Wednesday, and Thursday, March 20, 21, and 22, 1945, and the Mayo Hotel has been named headquarters. At the time of this announcement, 4 months in advance of the meeting, the plans are preliminary and subject to changes that may be necessitated by conditions of transportation, housing, *et cetera*. It is anticipated however, that this will be another war-time conference of the three organizations—the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists. Arrangements will be similar to those of recent years. The meeting will be restricted to business sessions and the most important technical and research conferences. There is to be no banquet, dance, golf tournament, or field trips.

BECAUSE OF LIMITED HOTEL SPACE, THERE WILL BE NO POSSIBILITY OF ACCOMMODATING WIVES. MEMBERS ARE REMINDED NOT TO COME TO THE MEETING UNLESS THEY HAVE A HOTEL CONFIRMATION OF A ROOM RESERVATION IN ADVANCE, OR UNLESS THEY HAVE A SPECIFIC ARRANGEMENT TO STAY IN A PRIVATE HOME. THE COMMITTEE CAN NOT OVEREMPHASIZE, UNDER WAR-TIME CONDITIONS, THE POSITIVE NEED FOR HAVING A DEFINITE AND CERTAIN ARRANGEMENT FOR ROOM ACCOMMODATIONS DURING THIS MEETING.

J. V. Howell, president of the Tulsa Geological Society, announces that the general chairman in charge of arrangements is W. B. Wilson, of the Gulf Oil Corporation, Tulsa. The chairmen of the various committees will be named and their usual activities will be planned, subject to developments in the coming months. Further announcement will be made in the *Bulletin*.

Although the limited oral program will not provide time for the delivery of papers other than those of a very general nature it is highly desirable that all who can prepare papers make an effort to submit titles, abstracts, and complete manuscripts which may be placed on the program BY TITLE, and later published in the *Bulletin*. Papers are needed for the monthly *Bulletin*, and it is desirable to include titles on the program of this meeting.

The executive committee desires to emphasize the necessity for limiting the attendance.

GEOLOGY OF BARCO CONCESSION, COLOMBIA—REPRINTS

The Association has a supply of separates of the article, "Geology of the Barco Concession, Republic of Colombia, South America," by FRANK B. NOTESTEIN, CARL W. HUBMAN, and JAMES W. BOWLER, recently published by the Geological Society of America. This is a unique contribution to the geology of South America. Published in English and with the permission of the operating companies, this is the first thorough geological description of this important region of petroleum development. It is expected that petroleum geologists will need copies of this outstanding article, and the Association is pleased to be able to announce the availability of reprints from the G.S.A. Bulletin. The price is $0.50 per copy, postpaid. The article contains 41 pp., 6 pls., and 12 figs. The geological map of the concession is a folded sheet, 15 x 30 inches, in colors, on the scale of 1 inch = 3 miles. Orders will be filled by writing A.A.P.G. Headquarters, Box 979, Tulsa 1, Oklahoma.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1666-1669, 1 FIG.

MEMORIAL

LEE HAGER
(1874–1944)

Lee Hager, pioneer geologist of the Texas Gulf Coast, a member of the American Association of Petroleum Geologists since 1918, died in Houston, Texas, on August 11, 1944. At the time of his death he was 70 years of age.

Mr. Hager was born in Denver, Colorado, on July 18, 1874, his parents being F. D. Hager and Sarah Dilworth Hager. He was educated in the public and grade schools in St. Paul, Minnesota, and was graduated from Harvard College in 1896. He served in the army during the Spanish-American war.

He came to Beaumont, Texas, in 1901, shortly after the Spindletop discovery, which initiated the oil development in the state of Texas. His first employment as geologist was with the Guffey Petroleum Company, now the Gulf Oil Corporation, the Guffey Petroleum Company being the company which financed Lucas in the discovery of the Spindletop field.

He was later employed as a geologist with the Rio Bravo Oil Company, under E. T. Dumble, and at that time was associated with L. P. Garrett, who later became vice-president of the Gulf Oil Corporation. Rio Bravo Oil Company at that time was one of the leading oil companies in the development of the Gulf Coast salt domes, notably Saratoga and Sour Lake, which quickly followed the discovery of Spindletop.

Hager left the Rio Bravo Oil Company about 1907 and later became associated with the well known Gulf Coast operator, E. F. Simms, during which time he did geological work and drilled a number of wells in Texas and Louisiana for Simms. He was interested with Simms in the promotion of the sulphur development of the Freeport dome in Brazoria County, Texas, which was later taken over by the Freeport Sulphur Company, organized at that time for the purpose of producing sulphur from this dome. The Freeport Sulphur Company has been one of the leading sulphur producers of the United States since that time.

After severing his connection with Simms, Hager operated as an independent, being active in the discovery of new domes and acquiring oil holdings in his own behalf. He was primarily responsible for the discovery of the Markham oil field in Matagorda County, Texas, and discovered the Section 28 Dome in St. Martin Parish, Louisiana, which sometimes is also known as the Hager dome. He was also among the first to discover the paraffine-dirt beds and gas seepages in the Goose Creek field of Harris County, Texas, although L. P. Garrett was on the ground at about the same time and Garrett is generally credited with this discovery.

The first oil holdings that Hager acquired on his own account were in the Goose Creek field. In 1916 he organized the Tide Water Oil Company, a company mainly interested in the acquisition of oil royalties, and in this company Hager placed the oil holdings which he had at that time. The company was very successful and was sold to L. P. Garrett in 1923.

Following this sale, Hager organized the Federal Royalty Company of Arizona, of which he was president since its organization in 1923 until the time of his death.

This company likewise has been very successful in the acquisition of producing oil royalties, owning, among others, important producing royalties in the Yates field of Pecos County, Texas, which Hager acquired prior to the discovery of this field.

In his later years Hager became interested in civic activities in his home city of Houston, Texas. He was chairman of the Recreation Asssociation of Houston since its

organization in 1928 and for the last 2 years had been president of the combined Parks and Recreation Association. During the depression he was chairman of the Harris County Welfare and Relief Board during its existence.

LEE HAGER

In his earlier years Hager published in the *Engineering and Mining Journal*, Vol. 78, pages 137 to 182, an article entitled "The Mounds of the Southern Oil Fields," which describes the general geology of the Gulf Coast region of Louisiana and Texas and the geologic structure of the salt domes, and discussed the theories of their origin. This article was published in 1904.

About 1918 there was distributed in the Gulf Coast a pamphlet entitled *Indications of Oil of the Gulf Coast Country, What They Are, How to Know Them.* This pamphlet was distributed with the compliments of W. C. Moore of Houston, Texas, but the article itself

was written by Hager and discussed very lucidly the surface showings of oil fields in the Gulf Coast which were relied upon for the discovery of these fields prior to the introduction of geophysics into this area.

Hager was among the first to recognize and identify the so-called "paraffine-dirt" which was found in association with many of the shallow piercement salt domes of the Gulf Coast and led to the early discovery of them: Batson, Humble, Pierce Junction, Goose Creek, Section 28 Dome, and several others.

He contributed to the discussion of an article by Albert Dudley Brokaw entitled "Interpretation of So-Called Paraffin Dirt of Gulf Coast Oil Fields" published in the *Transactions* of the American Institute of Mining and Metallurgical Engineers, Vol. 61, pages 482 to 500, in 1920.

In his later years he became interested in economic subjects and published three pamphlets on these subjects, the last of which appeared in 1943, entitled *Too Many People in the World*. Twenty thousand copies of this pamphlet were distributed.

In addition to his membership in the American Association of Petroleum Geologists, Hager had been a member of the American Institute of Mining and Metallurgical Engineers since 1904, being one of the oldest members of the Institute resident in Houston, at the time of his death.

He was also a member of the Houston Country Club and Houston Club.

He is survived by his sister, Mrs. Matthew D. Gilbert of Beverly Hills, Los Angeles, California, and by his two brothers, Dorsey Hager of Centralia, Illinois, and Dilworth S. Hager of Dallas, Texas, both of whom have likewise reputations as outstanding geologists.

ALEXANDER DEUSSEN

HOUSTON, TEXAS
September 11, 1944

JESSE HOMER DERDEN

(1890–1944)

It was with deep sorrow that the friends of J. H. Derden learned of his death. While he had been in failing health for several years, few, excepting his closest friends, realized the seriousness of his condition, because he continued to carry on his work until the end. He died from a heart attack on June 16, 1944, in Ardmore, Oklahoma. He had been on a business trip to Kansas and Oklahoma, and was returning to his home in San Antonio, Texas.

He was born in El Paso, Arkansas, March 3, 1890. He attended the University of Arkansas, graduating with an A.B. degree in 1915. During his college course (1912–13) he was employed by the Tennessee Geological Survey in making soil surveys in that state. After graduation, he taught in the public schools of Arkansas until 1917, when he was employed by the Indian Territory Illuminating Oil Company of Bartlesville, Oklahoma.

His first work was similar to that of many early-day field geologists. With stadia rod and plane table, they mapped the eastern parts of Kansas and Oklahoma. Their work demonstrated the practical application of geology to the production of oil and gas, and established the essential place of this science in oil industry to-day.

The first World War brought a temporary halt to his work. Homer enlisted and served 9 months in France with the 141st A.A. Machine Gun Battalion.

Soon after his discharge from the Army, he became a geologist for the Kentucky Producers Company. In 1920 he returned to the I.T.I.O. Company in Bartlesville, Oklahoma. An inherent love of the out-of-doors helped make him one of the best of the field geologists. This ability was recognized by his company, and he was advanced to the

position of chief field geologist. In this capacity he was able to train the younger geologists working for his company. They found him a tireless worker, a practical geologist, and an understanding friend. He continued in this position, and as a district geologist, while with the I.T.I.O. In 1933 he moved to San Antonio, and became a successful independent geologist, operating chiefly in Texas.

While working in Kansas, Homer met Miss Sadie McCoy. On August 19, 1922, they were married. The love and companionship she brought to him enriched his entire life. His family was always his first consideration, and his greatest happiness. Mrs. Derden and their three daughters, Mrs. H. E. Metcalf, Wilma Lois, and Elizabeth Joyce, survive him.

All who knew Homer will always cherish the memory of his steadfast loyalty to his ideals and to his friends.

C. W. ROOP

WICHITA, KANSAS
September, 1944

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGIST
VOL. 28, NO. 11 (NOVEMBER, 1944), PP. 1670-1672

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

KIRTLEY F. MATHER, professor of geology at Harvard University, has written a 186-page book entitled *Enough and To Spare*, published by Harper and Brothers. "(1) Co-operation, not competition, is the key to survival; (2) The earth's human population is not increasing faster than there are means for sustaining it; (3) the earth's non-renewable resources (coal, oil, iron, etc.) and its renewable resources (waterpower, etc.) are 'enough and to spare' for this generation and generations to come."

Major HUBERT G. SCHENCK has been assigned to overseas duty. Mail may be addressed to Box 1528, Stanford University, California.

E. T. MONSOUR is with the Shamrock Oil and Gas Corporation as district geologist and representative in Alabama, Mississippi, and Louisiana. His address is Box 2571, West Jackson 117, Mississippi.

A. B. GROSS is leaving the Mid-Continent Petroleum Corporation to go with John J. Fleet. His address is 1610 Alamo National Bank Building, San Antonio, Texas.

ROBERT B. TOTTEN, formerly in the employ of the Phillips Petroleum Company, is working in South Arkansas and North Louisiana for the Sun Oil Company.

Ensign C. W. PAYNE is in the Military Government School, Princeton University, Princeton, New Jersey.

Major PAUL K. GOODRICH is in the Field Artillery at Fort Bragg, North Carolina—Hq. XXII. Corps Arty.

CHARLES W. STERNBERG has left the Ohio Oil Company to become associated with the Atlantic Refining Company at Casper, Wyoming.

E. F. DAVIS, who has been vice-president in charge of production and geological work for the Shell Oil Company, Inc., on the Pacific Coast, is now vice-president and chief consulting geologist.

SHAPLEIGH G. GRAY has opened an office for consulting practice at 930 Esperson Building, Houston, Texas. He was district geologist for the Tide Water Associated Oil Company for the Louisiana and Mississippi district, with headquarters at Houston for the past 6 years, prior to which he was with The Texas Company for 11 years in the Shreveport and Fort Worth districts.

E. FLOYD MILLER, chief geologist with A. G. Oliphant, has returned to Tulsa, Oklahoma, after an absence of 7 years in Arkansas, Louisiana, and South Texas. His office address is 1905 National Bank of Tulsa Building.

J. O. NELSON has returned from army duty with the Corps of Engineers in England. He has reopened a consulting office in San Antonio, Texas, at 1428 Milam Building.

V. C. ILLING, professor of oil technology in the Imperial College of Science and Technology, London, has been awarded the Murchison medal of the Geological Society of London.

A. I. LEVORSEN, past-president of the Association, is one of the starred men of geological science in the most recent issue of *American Men of Science*. The star indicates the leading men in each of the several sciences.

JAMES E. KEENAN, recently with the Magnolia Petroleum Company is in the employ of the Bay Petroleum Corporation, Denver, Colorado.

Captain JUSTIN MATTHEW RUKAS is stationed at Spartanburg, South Carolina—132 Princeton Street.

WILLIAM H. ATKINSON, consulting geologist of Oklahoma City, spoke on "The Geology of the West Edmond Field, Oklahoma," before the Shawnee Geological Society at the September meeting.

Recently elected officers of the Panhandle Geological Society, Amarillo, Texas, are: president, A. B. VAN TINE, Gulf Oil Corporation; vice-president, CARY R. WAGNER, JR., Pure Oil Company; secretary-treasurer, E. W. SISNEY, Cities Service Gas Company. Since the election of officers Van Tine has been transferred out of this district, and Wagner has become president.

HORACE C. DAVIS has left The Texas Company to go with the Vickers Petroleum Company, Wichita, Kansas.

RAE PREECE is with the Hancock Oil Company, of California, at 404 Milam Building, San Antonio, Texas.

POWELL W. MILLER is 1st lieutenant in the Army Air Corps, as photograph interpreter stationed in China.

R. STANLEY BECK is a consulting paleontologist at Bakersfield, California. He was formerly with the Richfield Oil Corporation.

B. W. ALLEN, formerly with the Gulf Oil Corporation, at Tyler, Texas, is with the Woodley Petroleum Company, at Jackson, Mississippi.

Lieutenant JOHN B. LUCKE, U.S.N.R., on leave as head of the department of geology at the University of Connecticut, has been assigned to duty as photographic interpreter abroad. He may be addressed at J.I.C.P.O.A., Navy 128, Fleet Post Office, San Francisco, California.

JOHN C. CAMPBELL, recently in the department of geology at the University of North Carolina, is assistant professor in geology at Rutgers University, New Brunswick, New Jersey.

REGINALD G. RYAN has entered the employ of the Ashland Oil and Refining Company, Ashland, Kentucky, after directing the exploration program of Northern Ordnance, Inc., in Ohio during the past year.

JOE CANON has resigned from the geological staff of the Gulf Oil Corporation to do independent geological work at Midland, Texas.

The Midland (Texas) Geological Society has elected the following officers: president, GEORGE R. GIBSON, Richfield Oil Corporation; vice-president, LEO J. NEWFARMER, Shell Oil Company, Inc.; secretary-treasurer, JOHN HILLS; program chairman, ADDISON YOUNG, Phillips Petroleum Company. This is not the West Texas Geological Society of Midland.

DEAN C. WELLMAN has resigned from the Pure Oil Company at Tulsa, Oklahoma, to join the Shell Oil Company, Inc., at Centralia.

SHERRILL A. SHANNON, for 7 years with the Cities Service Oil Company, is now assistant district geologist for the Sunray Oil Corporation at Wichita, Kansas.

President IRA H. CRAM has recently visited several groups of geologists. On October 2 he addressed the New York Academy of Sciences on "Imagination in Petroleum Geology." At Cambridge, Massachusetts, he discussed a research program with members of the Association, together with members of the Harvard and Massachusetts Institute of Technology faculties.

Major R. H. BECKWITH, formerly professor of geology at the University of Wyoming, is with the United States Marines in the central Pacific region. He entered active service as a captain in 1942.

C. R. LONGWELL, professor of geology at Yale University, represented the A.A.P.G. and Yale University, at the inauguration of Homer L. Dodge as the 18th president of Norwich University, Vermont.

New officers of the East Texas Geological Society are: president, J. H. MCGUIRT, Magnolia Petroleum Company, Box 780; vice-president, R. M. TROWBRIDGE, Trowbridge Sample Service; and secretary-treasurer, RUSSELL FARMER, Stanolind Oil and Gas Company, Box 660; all of Tyler, Texas. Regular meetings are held at 7:30 P.M., the second Monday of each month, at the City Hall. Luncheons are held at noon on the fourth Monday of each month at the Blackstone Hotel.

Lieutenant GLENN D. HAWKINS, USNR, has been on a month's leave in continental United States after 18 months in the South Pacific. He has been personal adviser on the staffs of General Alexander M. Patch, Major General Oscar W. Griswold, Major General Roy M. Giger, and Vice-Admiral Theodore S. Wilkinson. He has received citations in the course of his activity in getting frontline information, for giving advice on water supplies, landing beaches, and topographic features pertaining to operations, particularly as a specialist on coral formations. Lieutenant Hawkins visited with his family and friends in Tulsa in October and reported for duty at Washington, D. C.

CECIL HAGEN, geologist, 2518 Gulf Building, Houston, Texas, has been released from active service in the United States Navy.

WILTON E. SCOTT recently resigned as district geologist for the Cities Service Oil Company at Hobbs, New Mexico, to become head of the land and geological department of the Maljamar Oil and Gas Corporation, Artesia, New Mexico.

MICHEL T. HALBOUTY has been promoted to the rank of Lieutenant Colonel, Infantry. His present position is chief of the petroleum production section of the Planning Division of the Army-Navy Petroleum Board, Washington, D. C.

Major HENRY ROGATZ is associated with the Photographic Division of the Air Corps Intelligence. His address is 1611 Park Road, N. W., Washington, D. C.

ROSCOE E. SHUTT has resigned his position of manager of the geology and exploration department of the Shell Oil Company, Inc., at Tulsa. He had been manager 11 years and had been with the company 20 years.

J. K. MURPHY has left the British-American Oil Producing Company at Tulsa to become chief geologist of the Norbla Oil Company, Tulsa.

DEAN A. MCGEE is executive vice-president of the Kerlyn Oil Company, Oklahoma City.

MAX W. BALL, of Denver, Colorado, has been appointed special assistant to Ralph K. Davies in the Petroleum Administration for War.

DISTINGUISHED LECTURE TOUR

Judson L. Anderson of the geological faculty at The Johns Hopkins University, Baltimore, Maryland, made a transcontinental tour during November, speaking on the subject "The Petroleum Geology of Colombia, South America" before sixteen affiliated societies of the Association. Dr. Anderson's address was based on many years of experience as an oil geologist in South America prior to joining The Johns Hopkins faculty.

His itinerary follows.

October	30	Joint meeting of Illinois Geological Society and Indiana-Kentucky Geological Society at Evansville, Indiana
November	1	Kansas Geological Society at Wichita
	2	Tulsa Geological Society at Tulsa
	3	Oklahoma City Geological Society at Oklahoma City
	4	Ardmore Geological Society at Ardmore
	6	Fort Worth Geological Society at Fort Worth
	9	Annual Meeting Pacific Section, A. A. P. G. at Los Angeles
	13	West Texas Geological Society at Midland
	14	Dallas Petroleum Geologists at Dallas
	15	Houston Geological Society at Houston
	17	North Texas Geological Society at Wichita Falls
	20	Shreveport Geological Society at Shreveport
	21	New Orleans Geological Society at New Orleans
	22	Mississippi Geological Society at Jackson

JOHN L. FERGUSON, *chairman*

TULSA, OKLAHOMA
October 20, 1944

PROFESSIONAL DIRECTORY

CALIFORNIA

J. L. CHASE
Geologist — Geophysicist
529 East Roosevelt Road
LONG BEACH CALIFORNIA
Specializing in Magnetic Surveys

PAUL P. GOUDKOFF
Geologist
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
LOS ANGELES, CALIFORNIA

VERNON L. KING
Petroleum Geologist and Engineer
707 South Hill Street
LOS ANGELES, CALIFORNIA
Vandike 7087

JEROME J. O'BRIEN
Petroleum Geologist
Examinations, Reports, Appraisals
Petroleum Building
714 West Olympic Boulevard
McCARTHY & O'BRIEN Los Angeles 15, Calif.

ERNEST K. PARKS
Consultant in
Petroleum and Natural Gas Development
and
Engineering Management
614 S. Hope St.
LOS ANGELES, CALIFORNIA

HENRY SALVATORI
Western Geophysical Company
711 Edison Building
601 West Fifth Street
LOS ANGELES, CALIFORNIA

RICHARD L. TRIPLETT
Core Drilling Contractor
WHitney 9876 2013 West View St.
LOS ANGELES 16, CALIF.

COLORADO

C. A. HEILAND
Heiland Research Corporation
130 East Fifth Avenue
DENVER, 9, COLORADO

COLORADO

HARRY W. OBORNE
Geologist
304 Mining Exchange Bldg. 230 Park Ave.
Colorado Springs, Colo. New York, N.Y.
Main 7525 Murray Hill 9-3541

ILLINOIS

CLARENCE E. BREHM
Geologist and Geophysicist
Box 502, Mt. Vernon, Illinois
725 Magnolia Ave. Phone 1643

ILLINOIS

ELMER W. ELLSWORTH
Consulting Geologist
201 Grand Theatre Building
132 North Locust Street
CENTRALIA, ILLINOIS
Now in military service

L. A. MYLIUS
Geologist *Engineer*
132 North Locust Street
Box 264, Centralia, Illinois

ILLINOIS

T. E. WALL

Geologist

Mt. Vernon Illinois

INDIANA

HARRY H. NOWLAN

Consulting Geologist and Engineer
Specializing in Valuations

Evansville 19, Indiana
317 Court Bldg. Phone 2-7817

LOUISIANA

WILLIAM M. BARRET, INC.

Consulting Geophysicists

Specializing in Magnetic Surveys

Giddens-Lane Building SHREVEPORT, LA.

G. JEFFREYS

Geologist *Engineer*

Specialist, Mississippi & Alabama

100 East Pearl Street
Box 2415 Depot P.O.
Jackson, Mississippi

NEW YORK

BROKAW, DIXON & McKEE

Geologists *Engineers*

OIL—NATURAL GAS

Examinations, Reports, Appraisals
Estimates of Reserves

120 Broadway New York
Gulf Building Houston

BASIL B. ZAVOICO

Petroleum Geologist and Engineer

220 East 42nd Street

NEW YORK 17, NEW YORK
MUrray Hill 2-6750

OHIO

JOHN L. RICH

Geologist

Specializing in extension of "shoestring" pools
University of Cincinnati
Cincinnati, Ohio

OKLAHOMA

ELFRED BECK

Geologist

717 McBirney Bldg. TULSA, OKLA.
Box 55 DALLAS, TEX.

FRANK BRYAN

Consulting Geologist

NELSON OKLAHOMA

R. W. Laughlin L. D. Simmons

WELL ELEVATIONS

LAUGHLIN-SIMMONS & CO.
615 Oklahoma Building

TULSA OKLAHOMA

A. I. LEVORSEN

Petroleum Geologist

221 Woodward Boulevard

TULSA 5 OKLAHOMA

OKLAHOMA

FRANK A. MELTON
Consulting Geologist
Aerial Photographs
and Their Structural Interpretation
1010 Chautauqua Norman, Oklahoma

CLARK MILLISON
Petroleum Geologist
Philtower Building
TULSA OKLAHOMA

C. L. WAGNER
Consulting Geologist
Petroleum Engineering
Geophysical Surveys
2259 South Troost Street
TULSA OKLAHOMA

G. H. WESTBY
Geologist and Geophysicist
Seismograph Service Corporation
Kennedy Building Tulsa, Oklahoma

PENNSYLVANIA

HUNTLEY & HUNTLEY
Petroleum Geologists
and Engineers
L. G. HUNTLEY
J. R. WYLIE, JR.
JAMES F. SWAIN
Grant Building, Pittsburgh, Pa.

TEXAS

JOSEPH L. ADLER
Geologist and Geophysicist
Contracting Geophysical Surveys
in Latin America
Independent Exploration Company
Esperson Building Houston, Texas

TEXAS

CHESTER F. BARNES
Geologist and Geophysicist
Petroleum Bldg. P.O. Box 266, Big Spring, Tex.

D'ARCY M. CASHIN
Geologist *Engineer*
Specialist Gulf Coast Salt Domes
Examinations, Reports, Appraisals
Estimates of Reserves
705 Nat'l Standard Bldg.
HOUSTON, TEXAS

CUMMINS, BERGER & PISHNY
Consulting Engineers & Geologists
Specializing in Valuations
1603 Commercial Standard Bldg.
Fort Worth 2, Texas
Ralph H. Cummins
Walter R. Berger
Chas. H. Pishny

E. DEGOLYER
Geologist
Esperson Building
Houston, Texas
Continental Building
Dallas, Texas

J. H. DEMING
Geophysicist
KEYSTONE EXPLORATION COMPANY
2813 Westheimer Road Houston, Texas

ALEXANDER DEUSSEN
Consulting Geologist
Specialist, Gulf Coast Salt Domes
1006 Shell Building
HOUSTON, TEXAS

TEXAS

DAVID DONOGHUE

Consulting Geologist

Appraisals - Evidence - Statistics

Fort Worth National Bank Building — FORT WORTH, TEXAS

J. E. (BRICK) ELLIOTT

Petroleum Engineer

108 West 15th Street — Austin, Texas

F. B. Porter, *President* — R. H. Fash, *Vice-President*

THE FORT WORTH LABORATORIES

Analyses of Brines, Gas, Minerals, Oil, Interpretation of Water Analyses. Field Gas Testing.

828½ Monroe Street — FORT WORTH, TEXAS

Long Distance 138

JOHN A. GILLIN

National Geophysical Company

Tower Petroleum Building

Dallas, Texas

W. G. Saville — J. P. Schumacher — A. C. Pagan

GRAVITY METER EXPLORATION CO.
TORSION BALANCE EXPLORATION CO.

Gravity Surveys

Domestic and Foreign

1347-48 ESPERSON BLDG. — HOUSTON, TEX.

CECIL HAGEN

Geologist

Gulf Bldg. — HOUSTON, TEXAS

L. B. HERRING

Geologist

Natural Gas — Petroleum

Driscoll Bldg. — CORPUS CHRISTI, TEXAS

JOHN M. HILLS

Consulting Geologist

Midland, Texas

Box 418 — Phone 1015

PALEONTOLOGICAL LABORATORY

R. V. HOLLINGSWORTH

Geologist

Box 51 — Phone 2359

MIDLAND, TEXAS

J. S. Hudnall — G. W. Pirtle

HUDNALL & PIRTLE

Petroleum Geologists

Appraisals — Reports

Peoples Nat'l. Bank Bldg. — TYLER, TEXAS

JOHN S. IVY

Geologist

1124 Niels Esperson Bldg., HOUSTON, TEXAS

W. P. JENNY

Consulting Geologist and Geophysicist

Specializing in MICROMAGNETIC SURVEYS, GEOLOGICAL INTERPRETATIONS and CORRELATIONS of seismic, gravimetric, electric and magnetic surveys.

1404 Esperson Bldg. — HOUSTON, TEXAS

TEXAS

MID-CONTINENT TORSION BALANCE SURVEYS
SEISMIC AND GRAVITY INTERPRETATIONS

KLAUS EXPLORATION COMPANY

H. KLAUS

Geologist and Geophysicist

115 South Jackson, Enid, Oklahoma
2223 15th Street, Lubbock, Texas

JOHN D. MARR

Geologist and Geophysicist

SEISMIC EXPLORATION, INC.

Gulf Building Houston, Texas

HAYDON W. McDONNOLD

Geologist and Geophysicist

KEYSTONE EXPLORATION COMPANY

2813 Westheimer Road Houston, Texas

DABNEY E. PETTY

10 Tenth Street

SAN ANTONIO, TEXAS

No Commercial Work Undertaken

J. C. POLLARD

Robert H. Ray, Inc.

Rogers-Ray, Inc.

Geophysical Engineering

Gulf Building Houston, Texas

ROBERT H. RAY

ROBERT H. RAY, INC.

Geophysical Engineering

Gravity Surveys and Interpretations

Gulf Bldg. Houston, Texas

F. F. REYNOLDS

Geophysicist

SEISMIC EXPLORATIONS, INC.

Gulf Building Houston, Texas

WM. H. SPICE, JR.

Consulting Geologist

2101-02 Alamo National Building

SAN ANTONIO, TEXAS

HARRY C. SPOOR, JR.

Consulting Geologist

Petroleum . . . . . Natural Gas

Commerce Building Houston, Texas

CHARLES C. ZIMMERMAN

Geologist and Geophysicist

KEYSTONE EXPLORATION COMPANY

2813 Westheimer Road Houston, Texas

WEST VIRGINIA

DAVID B. REGER

Consulting Geologist

217 High Street

MORGANTOWN WEST VIRGINIA

WYOMING

E. W. KRAMPERT

Geologist

P.O. Box 1106

CASPER, WYOMING

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - Ben H. Parker
Colorado School of Mines, and Frontier Refining Company
1st Vice-President - - - - - - Dart Wantland
Colorado School of Mines
2nd Vice-President - - - - Wm. B. Kramer
U. S. Geological Survey
Secretary-Treasurer - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - - Robert F. Eberle
The Superior Oil Company

Vice-President - - - - - - - Stanley G. Elder
Sun Oil Company

Secretary-Treasurer - - - - Hillard W. Bodkin
The Superior Oil Company

Meetings will be announced.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Vice-President and Program Chm. - - - - - - - - - - - - - - - B. E. Bremer
The Texas Company, P.O. Box 252
Secretary Treasurer - - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - - - C. B. Roach
Shell Oil Company, Inc., Box 136
Vice-President - - - - - - - P. S. Shoeneck
Atlantic Refining Company
Secretary - - - - - - - - - - Ben F. Morgan
Stanolind Oil and Gas Company
Treasurer - - - - - - - - Robert N. Watson
Atlantic Refining Company, Box 895

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Fred H. Moore
Magnolia Petroleum Co., Box 535, Mt. Vernon

Vice-Presidents - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Secretary-Treasurer - - - - Everett F. Stratton
Schlumberger Well Surveying Corporation, Box 491, Mattoon

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - - Leo R. Fortier
Alpine Oil and Royalty Co.
Vice-President - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Secretary-Treasurer - - - - Delbert J. Costa
Superior Oil Co. of California
417 First Natl. Bank Bldg.
Manager of Well Log Bureau - Harvel E. White

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Visitors cordially welcomed.

The Society sponsors the Kansas Well Log Bureau which is located at 412 Union National Bank Bldg.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - R. M. Wilson
Ohio Oil Company, Drawer 1129, Zone 91
Vice-President - - - - - - - - E. P. Ogier
c/o W. C. Spooner, Box 1195, Zone 90
Secretary-Treasurer - - - - - L. H. Meltzer
Union Producing Co., Box 1407, Zone 92

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - Edward J. Baltrusaitis
Gulf Refining Company, Box 811, Saginaw
Vice-President - - - - - Raymond S. Hunt
Consulting, 405 S. Main, Mt. Pleasant
Secretary-Treasurer - - - - Thomas S. Knapp
The Chartiers Oil Co., Box 227, Mt. Pleasant
Business Manager - - - - - - Lee S. Miller
Michigan Geological Survey,
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - L. R. McFarland
Magnolia Petroleum Company
Vice-President - - - - - - - - J. B. Storey
Union Producing Company
Secretary-Treasurer - - - - Frederic F. Mellen
British-American Oil Producing Company
1007 Tower Building

Meetings: First and third Wednesdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - - John Marshall
The Texas Company, Box 539
Vice-President - - - - - - - Frank Neighbor
Sinclair Prairie Oil Company
Secretary-Treasurer - - - - - - - S. L. Rose
618 Simpson Building

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - - E. G. Dahlgren
Interstate Oil Compact Commission
State Capitol
Vice-President - - - - - Theodore G. Glass
Sinclair Prairie Oil Company
703 Colcord Building
Secretary-Treasurer - - - - - - C. E. Hamilton
Consolidated Gas Utilities Corporation
814 Braniff Building

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every Thursday, at 12:00 noon. Y.W.C.A. Cafeteria.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - Roy D. McAninch
Stanolind Oil and Gas Company, Box 1099
Vice-President - - - - - - - - E. R. Owen
Phillips Petroleum Company, Box 152
Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - J. V. Howell
1506 Philtower
1st Vice-President - - - - - - W. H. Butt
Atlantic Refining Company
2nd Vice-President - - - - W. Reese Dillard
Consulting
Secretary-Treasurer - - - - - - - V. G. Hill
Stanolind Oil and Gas Company, Box 591
Editor - - - - - - - - - - Roy L. Ginter
U. S. Geological Survey

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - - Ira H. Stein
Continental Oil Company, 604 Driscoll Building
Vice-President - - - - - Henry D. McCallum
Humble Oil and Refining Company
Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 904 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - Joseph M. Wilson
Continental Building
Vice-President - - - - - - - Henry C. Cortes
Magnolia Petroleum Company
Secretary-Treasurer - - - - H. C. Vanderpool
Seaboard Oil Company
Executive Committee - - - - Cecil H. Green
Geophysical Service, Inc.

Meetings: Regular luncheons, first Monday of each month, 12:00 noon, Petroleum Club, Adolphus Hotel. Special night meetings by announcement.

TEXAS

EAST TEXAS GEOLOGICAL SOCIETY

TYLER, TEXAS

President - - - - - - - - J. H. McGuirt
Magnolia Petroleum Company, Box 780

Vice-President - - - - - R. M. Trowbridge
Trowbridge Sample Service

Secretary-Treasurer - - - - - Russell Farmer
Stanolind Oil and Gas Company, Box 660

Meetings: Regular meetings at 7:30 P.M., the second Monday, each month, City Hall.
Luncheons: Noon, fourth Monday, each month, Blackstone Hotel.

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - Joseph H. Markley, Jr.
The Texas Company, Box 1720

Vice-President - - - - - - James L. Morris
The Pure Oil Company, Box 2107

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - - W. B. Milton, Jr.
Gulf Oil Corporation, Box 2100

Vice-President - - - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Secretary - - - - - - - - Charles H. Sample
J. M. Huber Corporation, 721 Bankers Mortgage Building

Treasurer - - - - - - - - Homer A. Noble
Magnolia Petroleum Company, Box 111

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - - - - - Donald Kelly
The Texas Company

Vice-President - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Secretary-Treasurer - - - David T. Richards
Shell Oil Co., Inc., Box 2010

Luncheons and evening programs will be announced.

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO, TEXAS

President - - - - - - - - Robert N. Kolm
Atlantic Refining Co., 1742 Milam Building

Vice-President - - - - - Donald O. Chapell
Transwestern Oil Co., 1600 Milam Building

Secretary-Treasurer - - - Robert D. Mebane
Saltmount Oil Co., 916 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST TEXAS GEOLOGICAL SOCIETY

MIDLAND, TEXAS

President - - - - - - - Robert I. Dickey
Forest Development Corporation

Vice-President - - - - - George R. Gibson
Richfield Oil Corporation

Secretary-Treasurer - - - - - - Jane Ferrell
Magnolia Petroleum Company, Box 633

Meetings will be announced

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P. O. Box 2385

President - - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - - Velesir C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - - Charles E. Stout
United Fuel Gas Company, Box 1275

Editor - - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June, July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston, Texas

Vice-President - - - - - - Henry C. Cortes
Magnolia Petroleum Company, Dallas, Texas

Editor - - - - - - - - - Joseph A. Sharpe
Stanolind Oil and Gas Company, Tulsa, Oklahoma

Secretary-Treasurer - - - - W. Harlan Taylor
Petty Geophysical Engineering Company
1449 Esperson Bldg., Houston, Texas

Past-President - - - - - - - R. D. Wyckoff
Gulf Research and Development Company
Pittsburgh, Pennsylvania

Business Manager - - - - - - J. F. Gallie
P.O. Box 410, El Dorado, Arkansas

McCullough GUN PERFORATOR COMPLETION METHODS —No. 5—

Gun-Perforate to REHABILITATE OLD WELLS

The nation needs a huge number of new flush-production wells to meet war demands for oil. It also needs every barrel of oil that can be produced from old wells. Gun perforating offers the most economical and quickly accomplished means of rehabilitating thousands of wells which are now producing little or no oil because the oil simply can't get into the well.

McCullough Gun Perforators employ a heavier propelling charge which drives the bullet with high velocity through multiple strings of casing and far into the formation. Thus new, clean channels are formed for flow of oil into the well, for washing behind the pipe, injecting acid, or for gas or fluid-drive recovery operations.

Experienced oil men operate McCullough Gun Perforators in all United States fields. They have a thorough knowledge of the results that can be expected in rehabilitating old wells by the McCullough Gun Perforator re-completion methods. Call the nearest McCullough office for service—day or night.

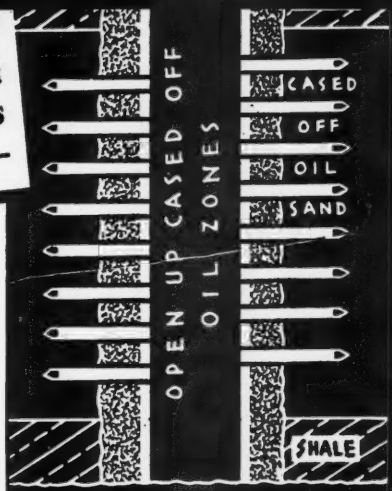
For Dependable Performance, Use the

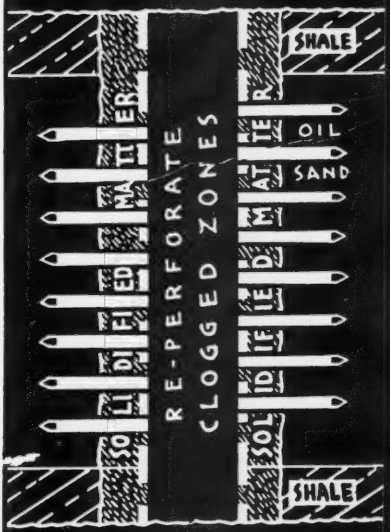
Hard Shooting-exact SPACING

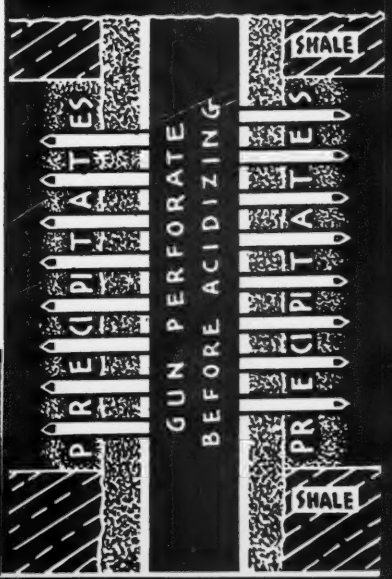
McCullough

GUN PERFORATOR

Refer to your 1944 Composite Catalog







22 SERVICE LOCATIONS

McCULLOUGH TOOL COMPANY . . . 5820 South Alameda Street, Los Angeles 11, California

Export Office: 30 Rockefeller Plaza, New York 20, N.Y.

HOUSTON, TEXAS
WICHITA FALLS, TEXAS
VICTORIA, TEXAS
CORPUS CHRISTI, TEXAS
GEO. WEST, TEXAS
ODESSA, TEXAS
TYLER, TEXAS
McALLEN, TEXAS
ALICE, TEXAS
MAGNOLIA, ARK.
NEW IBERIA, LA.
SHREVEPORT, LA.
HOUMA, LA.
LAKE CHARLES, LA.
OKLA. CITY, OKLA.
SEMINOLE, OKLA.
CASPER, WYO.
LOS ANGELES, CALIF.
VENTURA, CALIF.
BAKERSFIELD, CALIF.
AVENAL, CALIF.
SACRAMENTO, CALIF.

FIRST IN OIL FINANCING

1895-1944

THE FIRST NATIONAL BANK AND TRUST COMPANY OF TULSA

MEMBER FEDERAL DEPOSIT INSURANCE CORPORATION

THE GEOTECHNICAL CORPORATION

Roland F. Beers
President

1702 Tower Petroleum Building

Telephone L D 101 Dallas, Texas

LUFKIN

CHROME CLAD STEEL TAPES

"ATLAS"
King of all
Gaging Tapes

The outstanding development in the manufacture of measuring tapes

Features of all Chrome Clad Tapes:
Easy to read markings that are durable
Line resists rust, will not crack, chip or peel
Line is extra strong.

Send for Catalog No. 12 showing complete line of Tapes, Rules and Precision Tools

THE LUFKIN RULE CO.

Saginaw, Michigan New York City

JOURNAL OF SEDIMENTARY PETROLOGY

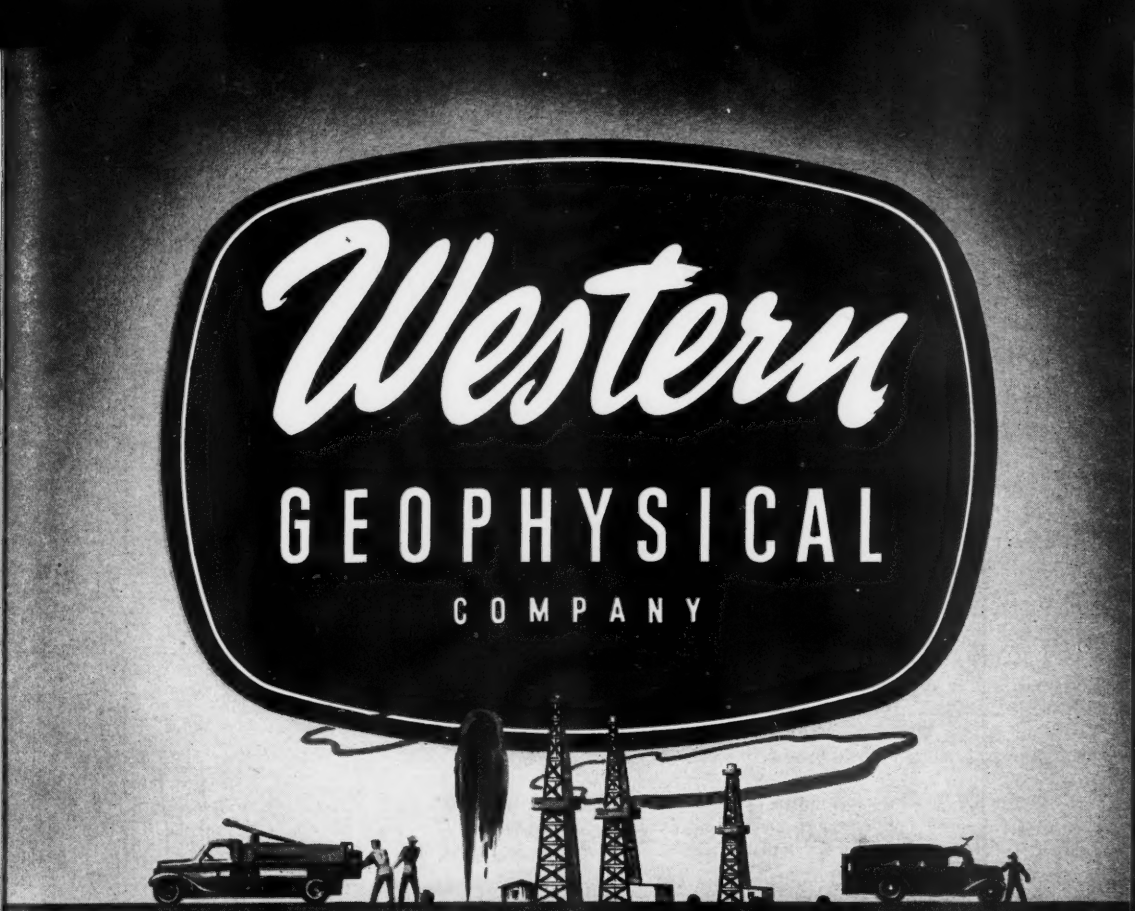
Three numbers constitute the volume for 1944. Subscription: $3.00.

JOURNAL OF PALEONTOLOGY

Six numbers constitute the volume for 1944. The only American journal devoted to this field. Subscription: $6.00 per year.

These publications of the Society of Economic Paleontologists and Mineralogists should be in the library of all working geologists.

Write S.E.P.M., Box 979, Tulsa 1, Oklahoma.



Complete geophysical exploration service for surveys in any part of the world.

Western GEOPHYSICAL COMPANY

HENRY SALVATORI, PRESIDENT

EDISON BLDG., LOS ANGELES, CALIF. ★ PHILCADE BLDG., TULSA, OKLA. ★ ESPERSON BLDG., HOUSTON, TEXAS

PRACTICAL PETROLEUM ENGINEERS' HANDBOOK

SECOND EDITION

Revised and Enlarged

By JOSEPH ZABA

and

W. T. DOHERTY

This book was written by practical oil men. The tables were compiled so that they can be used by anyone to meet practical field situations without further calculations, and will fit 99% of the conditions under which the average operator is working in the field.

The second edition of the PRACTICAL PETROLEUM ENGINEERS' HANDBOOK has been completely revised and enlarged. Many changes which have been made in the Standard Specifications of the American Petroleum Institute, particularly in pipe specifications, are incorporated in this second edition. Several tables are rearranged and charts enlarged to facilitate their use. Table of Contents and Index are more complete. Also about 90 pages of new formulae, tables, charts and useful information have been added.

This handbook was compiled and published for the purpose of saving the time of operators, engineers, superintendents, foremen and others.

TABLE OF CONTENTS

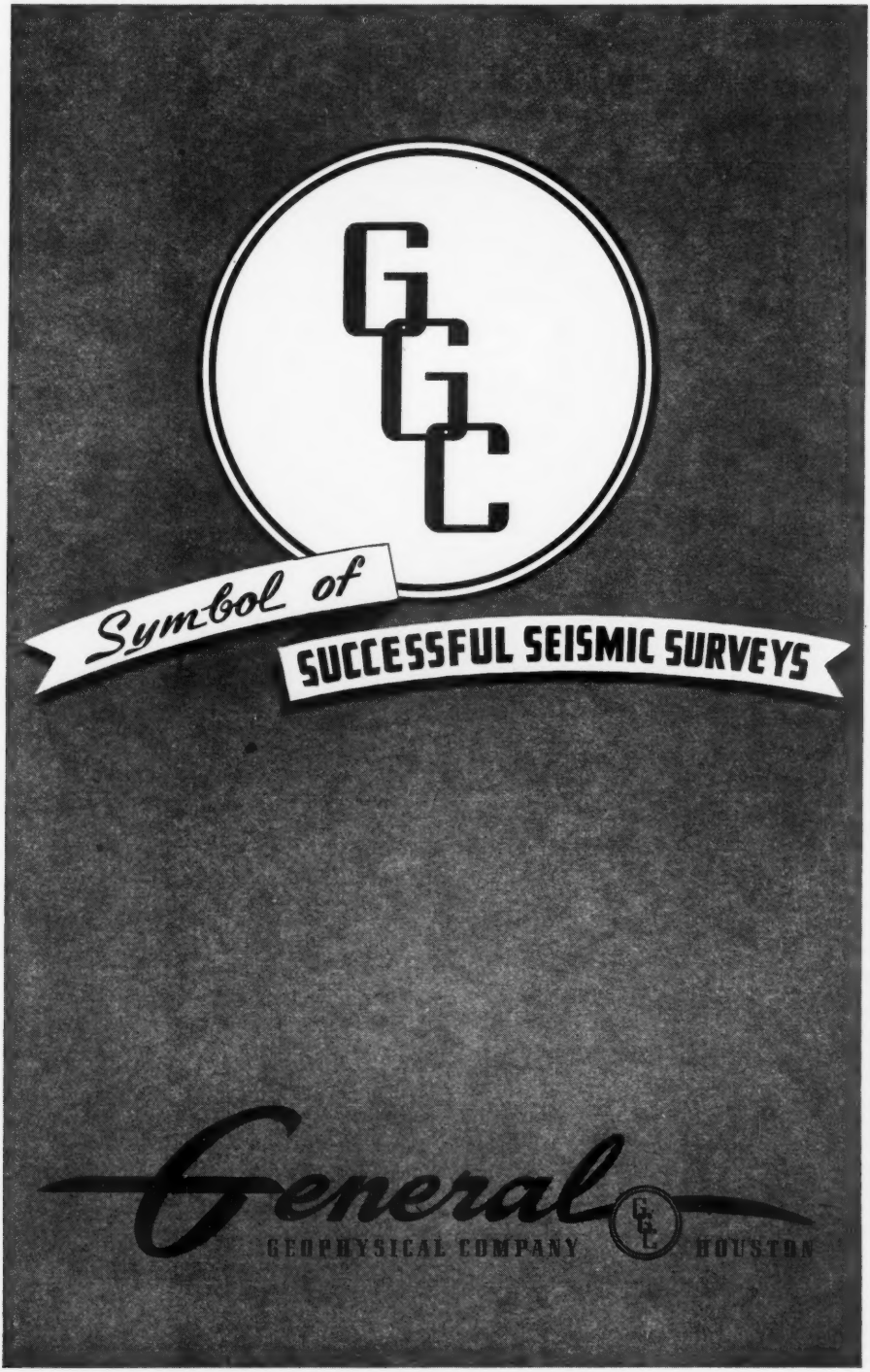
Chapter I —General Engineering Data
Chapter II —Steam
Chapter III —Power Transmission
Chapter IV —Tubular Goods
Chapter V —Drilling
Chapter VI —Production
Chapter VII —Transportation

Semi-Flexible Fabrikoid Binding, size 6 x 9, 492 Pages. Price: $5.00 Postpaid

Send Checks to the

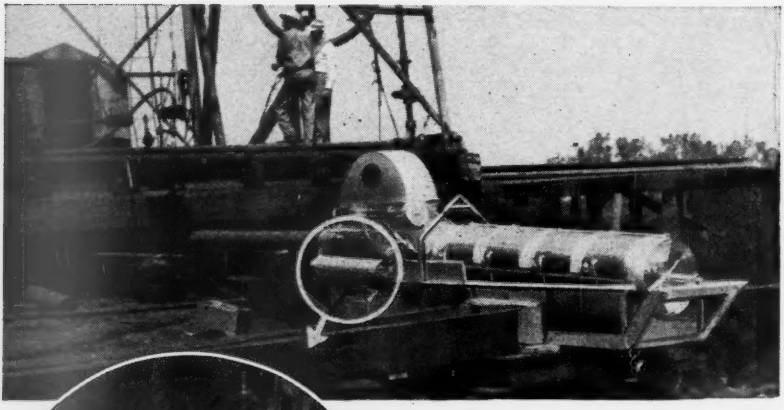
GULF PUBLISHING COMPANY

P. O. BOX 2608, HOUSTON, TEXAS


GGC
Symbol of
SUCCESSFUL SEISMIC SURVEYS
General
GEOPHYSICAL COMPANY
GGC
HOUSTON

THE GEOLOGIST'S BEST FRIEND

TRUE SAMPLES OF FOOT BY FOOT CUTTINGS PROVIDED BY THOMPSON MACHINE



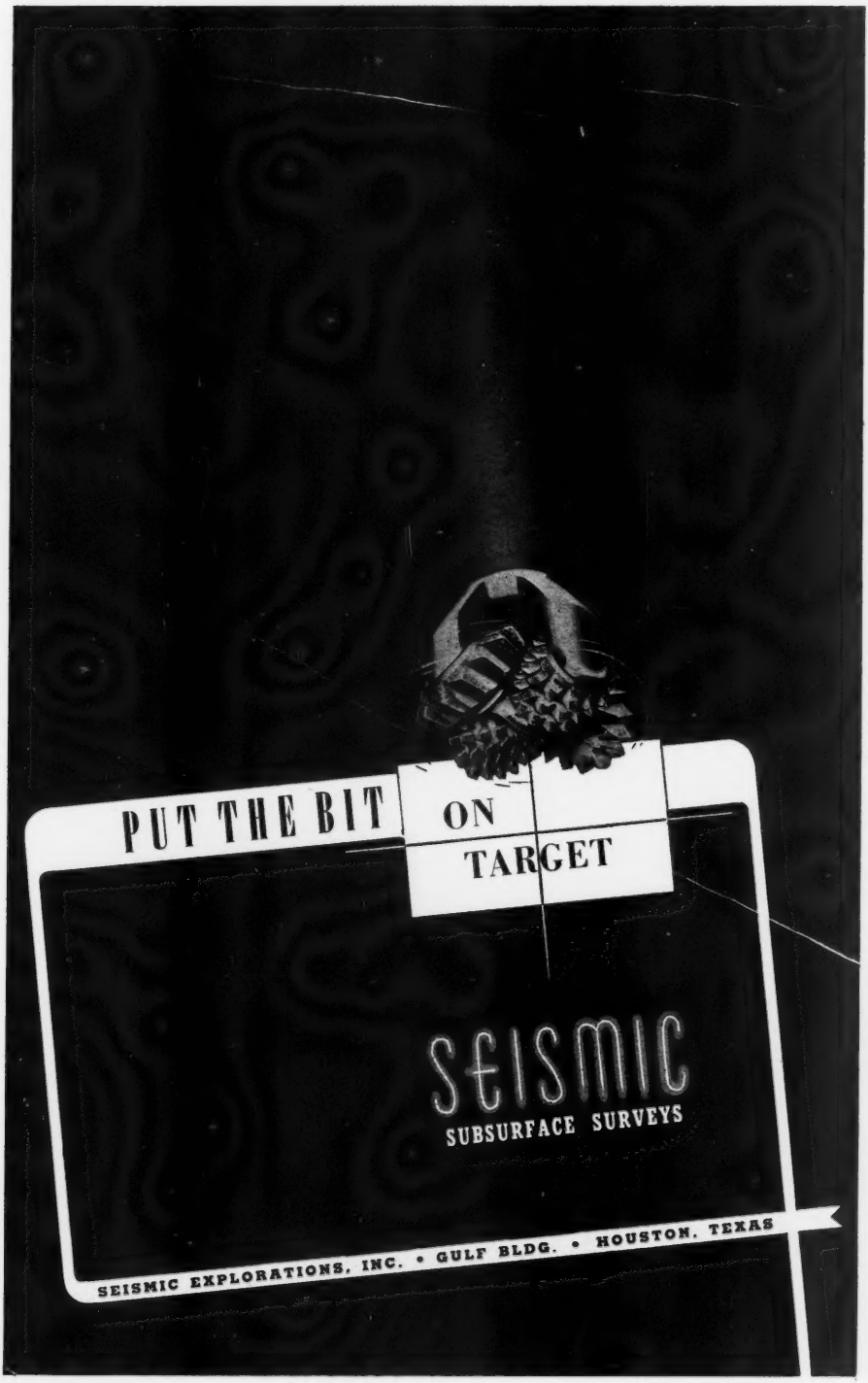
As simple as reading a log—that's what geologists and drilling operators say about foot by foot cuttings obtained from the THOMPSON SAMPLE MACHINE, which is standard equipment on all Thompson Shale Separators. Samples easily obtained and ready to analyze. Sample machine alone is worth the full cost of the Thompson Separator.

Manufactured by

THOMPSON TOOL CO., INC.

Sold Through Supply Stores Everywhere

Phone 3521 Iowa Park, Texas


PUT THE BIT ON TARGET
SEISMIC
SUBSURFACE SURVEYS
SEISMIC EXPLORATIONS, INC. • GULF BLDG. • HOUSTON, TEXAS

TRIANGLE BLUE PRINT & SUPPLY COMPANY

Representing
W. & L. E. Gurley
Spencer Lens American Paulin

Complete Reproduction Plant
Instruments Repaired

12 West Fourth Street, Tulsa, Oklahoma

TECTONIC MAP OF SOUTHERN CALIFORNIA
By R. D. Reed and J. S. Hollister

In 10 colors. From "Structural Evolution of Southern California," *BULL. A.A.P.G.* (Dec., 1936). Scale, ⅛ inch = 1 mile. Map and 4 structure sections on strong ledger paper, 27 x 31 inches, rolled in tube, postpaid, $0.50.

The American Association of Petroleum Geologists, Box 979, Tulsa 1, Oklahoma

GEOLOGY OF NATURAL GAS

EDITED BY HENRY A. LEY

• •

A comprehensive geologic treatise of the occurrence of natural gas on the North American Continent.

• •

1227 pages
250 illustrations
Bound in cloth. 6 x 9 x 2 inches

$4.50 Postpaid

$6.00 to non-members

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

Box 979, Tulsa 1, Oklahoma

The Annotated

Bibliography of Economic Geology

Vol. XV

Orders are now being taken for the entire volume at $5.00 or for individual numbers at $3.00 each. Volumes I-XIV can still be obtained at $5.00 each.

The number of entries in Vol. XV, No. 1, is 1,079. No. 2 is being printed.

Of these, 266 refer to *petroleum, gas,* etc., and *geophysics.* They cover the world, so far as information is available in war time.

If you wish future numbers sent you promptly, kindly give us a *continuing* order.

An Index of the 10 volumes was issued in May, 1939. Price: $5.00

Economic Geology Publishing Co.
Urbana, Illinois, U.S.A.

AERIAL PHOTOGRAPHY
RECONNAISSANCE MOSAICS
PRECISE AERIAL MOSAICS
TOPOGRAPHIC SURVEYS

For information write Department H

AERO SERVICE CORPORATION
Since 1919
PHOTOGRAMMETRIC ENGINEERS
236 E. Courtland Street, Philadelphia 20, Penna.

Check!

1 ✓ ★

2 ✓

3 ✓

YOU CAN...

1—Locate cased-off potential horizons.

2—Select accurately zones to be perforated.

3—Obtain maximum secondary production.

Here are the "Reasons Why"

Complete details of Radioactivity Well Logging applications, service and equipment together with sample logs from Gulf Coast, Mid-Continent and California fields are available on request. Write today for your copy.

Radioactivity Well Logging licensed by Well Surveys, Inc. • Tulsa, Oklahoma

Radioactivity Well Logging

Radioactivity Well Logging reveals the depths and thickness of all potential horizons in a well, through as many as three strings of casing. The curves are not affected by the nature of the well fluid. The accurate location of these potential zones aids materially in the development of an effective remedial program and permits selective testing for secondary productions.

Check these three Radioactivity Well Logging applications and "Call Lane-Wells"...

Tomorrow's Tools - Today!

LANE-WELLS

Pioneers in Oil Field Electronics

LOS ANGELES • HOUSTON • OKLAHOMA CITY

General Offices, Export Office and Plant:
5610 So. Soto St., Los Angeles 11, California

24-HOUR SERVICE • 30 BRANCHES

FEDERAL ELECTRIC COMPANY, INC.

Announces

another new Plastic Division Service Branch

for

Fedralite *Plastic* SHOT HOLE CASING

AT

Jennings

Louisiana

Fedralite is the plastic shot hole casing that is *made for the job.* It is light, easy to handle, strong. Its light weight makes it easier on men and equipment, more economical to ship and haul, more economical to use.

It gives excellent recovery, and a low cost per foot of holes shot. It has been fully proved, and is in regular use by many seismograph crews working in various kinds of territory.

To reduce exploration costs, save manpower, materials, and equipment—use Fedralite. Order a supply now, from any of the service branches listed at left.

YOU CAN GET

Fedralite *Now*

AT ANY OF THESE SIX POINTS

CHICAGO, ILLINOIS
8700 S. State Street

HOUSTON, TEXAS
700 Waugh Drive

DALLAS, TEXAS
1902 Field Street

NEW ORLEANS, LOUISIANA
730 St. Charles Street

THIBODAUX, LOUISIANA
Phone Thib. 3715

JENNINGS, LOUISIANA
Phone 430

PLASTICS DIVISION

FEDERAL ELECTRIC COMPANY, INC.

8700 SOUTH STATE STREET, CHICAGO 19, ILLINOIS

FEDELCO PLASTIC PIPES

Precision
Seismic Surveys!
National
GEOPHYSICAL
COMPANY INC.
DALLAS • TEXAS
Latest design Instruments
Appropriate Techniques
Versatile Equipment
Experienced Personnel
= Precision

For Your Library on South America

GEOLOGY OF THE BARCO CONCESSION

REPUBLIC OF COLOMBIA SOUTH AMERICA

BY

FRANK B. NOTESTEIN, CARL W. HUBMAN AND JAMES W. BOWLER

(PUBLISHED WITH THE PERMISSION OF THE COLOMBIAN PETROLEUM COMPANY)

CONTENTS

History of Exploration
Metamorphic and Igneous Rocks
Stratigraphy
  Cretaceous
  Tertiary
  Recent
Surface Indications of Petroleum
  Oil and Gas Seeps
  Asphaltic Dikes
  Hydrocarbon Residues
Structure
  Regional
  Petrolea-Tarra Anticlinorium
  Foothills Folds
  Folds of the Sardinata Depression
Development
  Rio de Oro Field
  Petrolea Field
  Carbonera Field
  Tres Bocas Field
  Socuavo Field

- THIS IS A SEPARATE ("REPRINT") FROM THE BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA, OCTOBER, 1944
- 51 PAGES, 4 FULL-TONE PLATES
- 10 COLUMNAR SECTIONS AND STRATIGRAPHIC CORRELATION CHARTS, 1 STRUCTURAL CONTOUR MAP, 1 WATER ANALYSIS CHART
- GEOLOGICAL MAP AND 2 CROSS SECTIONS IN COLORS (FOLDED INSERT, APPROX. 15 x 30 INCHES)

PRICE, 50 CENTS, POSTPAID

Order from

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA 1, OKLAHOMA, U.S.A.

Formation Information Thru Mud Analysis

BAROID
WELL LOGGING
SERVICE

Accurately determines formation content while drilling

BAROID WELL LOGGING SERVICE provides a successful method of determining the presence or absence of oil or gas in the various formations encountered while drilling, and of logging the depths and approximate thicknesses of such formations. The method is simple and also gives the operator additional information which heretofore has never been available and which enables him to drill a well more intelligently and with greater freedom from drilling difficulties.

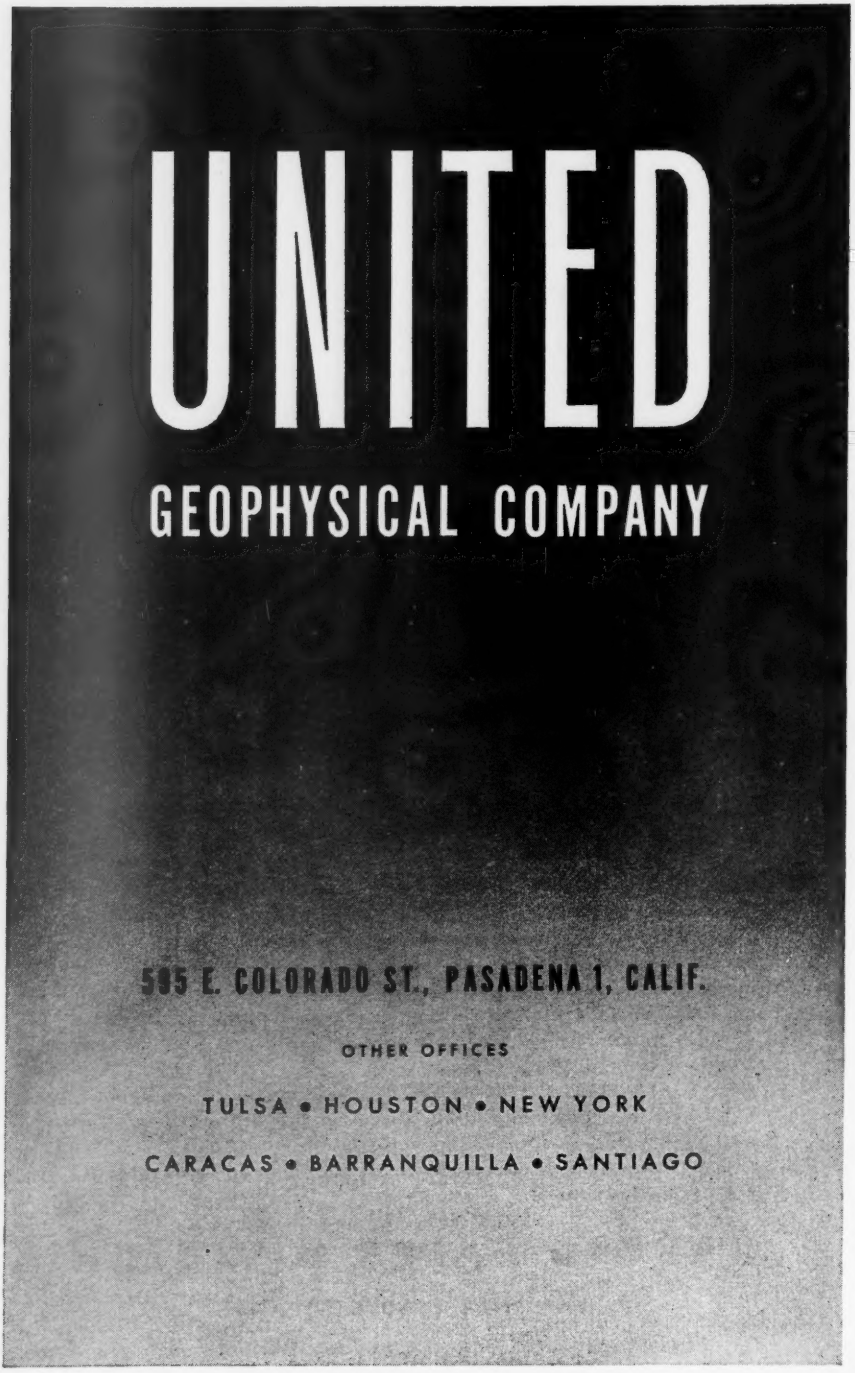
BAROID WELL LOGGING SERVICE has minimized coring in many fields and has been highly successful in the drilling of wildcat and exploratory wells.

Units, with trained operators, are available in oil fields throughout the United States.

BAROID SALES DIVISION

NATIONAL LEAD COMPANY

BAROID SALES OFFICES: LOS ANGELES 12 • TULSA 3 • HOUSTON 2


UNITED
GEOPHYSICAL COMPANY
505 E. COLORADO ST., PASADENA 1, CALIF.
OTHER OFFICES
TULSA • HOUSTON • NEW YORK
CARACAS • BARRANQUILLA • SANTIAGO

Accurate ALTITUDE READINGS

FOR THE GEOLOGIST

through PRECISE ALTIMETRY

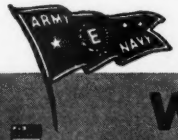
Altimetry employing the W&T Sensitive Altimeter provides the geologist with a fast and accurate means of determining altitudes in relation to known elevations.

Shock mounted in a 6 x 6 x 4 inch hardwood case and weighing only 2½ pounds, the instrument incorporates the portability and ruggedness essential in geophysical exploration.

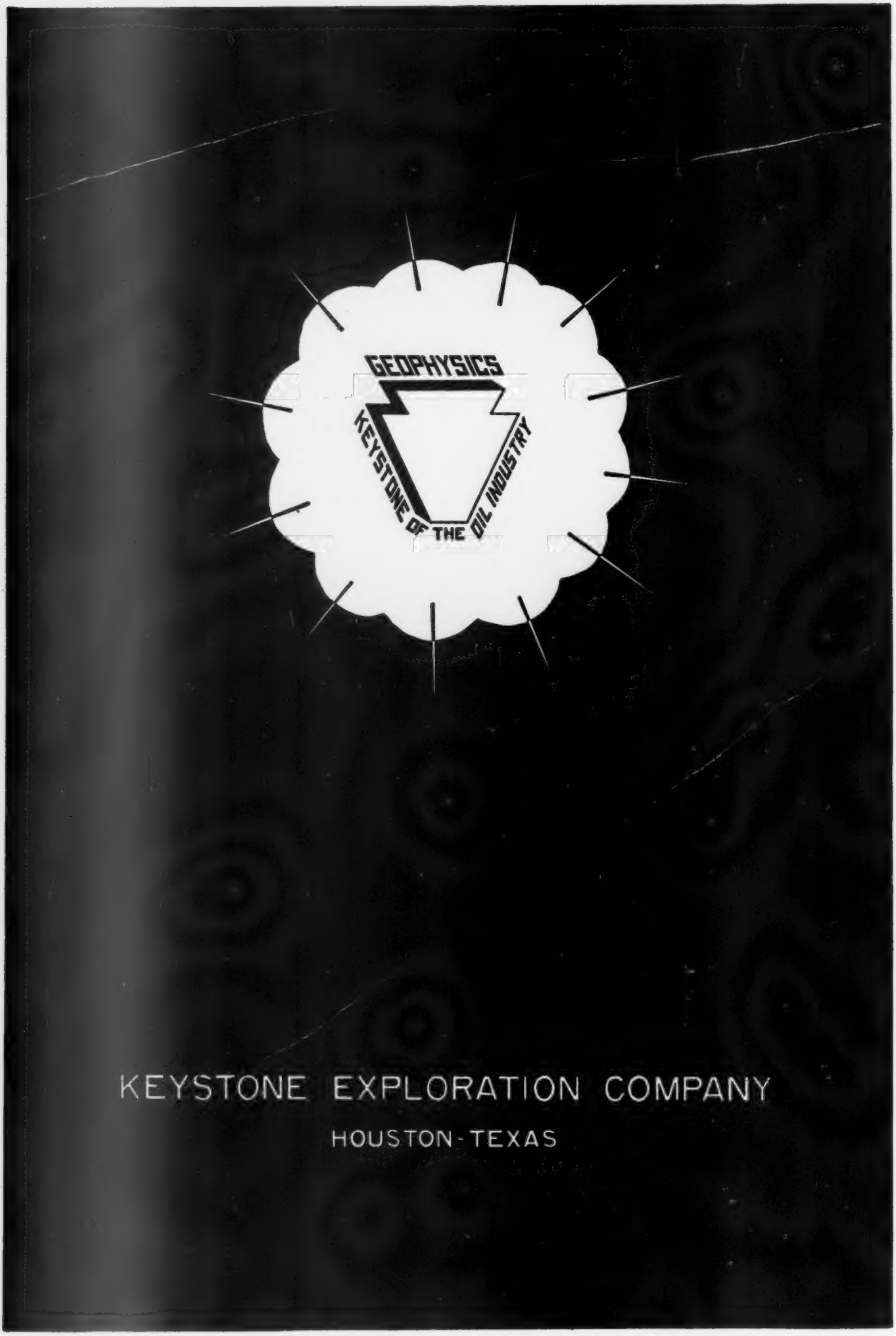
Two individually calibrated ranges are available: 0-7000 feet and 0-16000 feet, each temperature compensated for precise observations.

Write for illustrated technical bulletins.

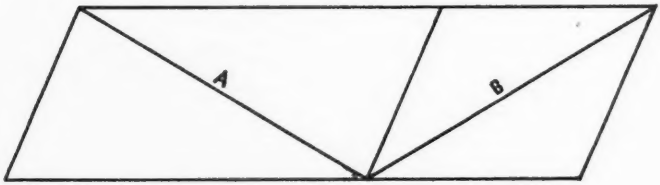
A-22



WALLACE & TIERNAN
PRODUCTS, INC.
BELLEVILLE 9 NEW JERSEY


GEOPHYSICS
KEYSTONE OF THE OIL INDUSTRY
KEYSTONE EXPLORATION COMPANY
HOUSTON-TEXAS

(FOR CABLE TOOL OPERATORS ONLY)



Is Line A Longer Than Line B?

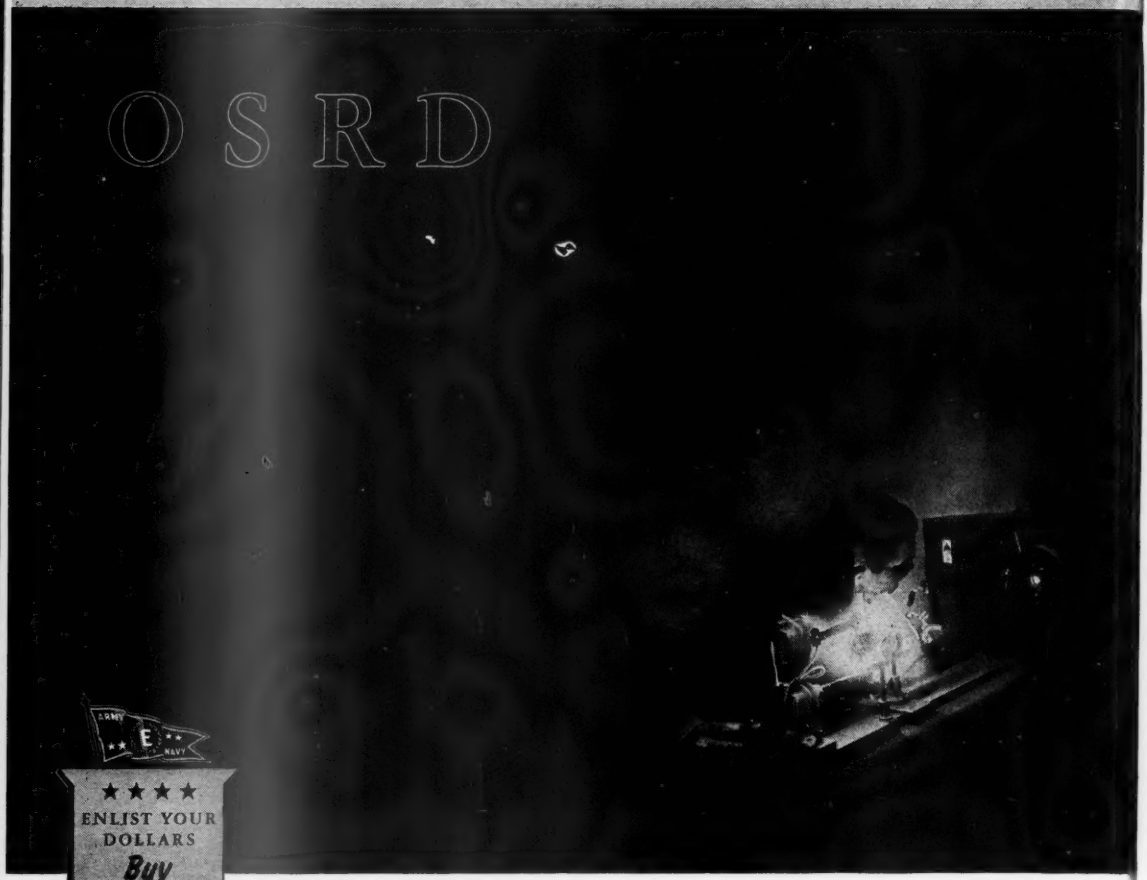
Things are *not* always what they appear to be, and that is why modern geologists use the Baker Cable Tool Core Barrel to secure a true cross section of the actual formation for detailed examination and analysis.—This simple, long-lasting tool is easy and inexpensive to use, and consistent results always pay their own way. Take time to look on Pages 370-374 of the 1944 Baker (or Composite) Catalog, or ask any Baker representative for the facts.

BAKER OIL TOOLS, INC.

Houston • LOS ANGELES • New York

The influence of angles of varying degrees makes Line A appear to be far longer than Line B, yet both measure the same. Geometry abounds in such optical illusions.

BRING YOUR OPTICAL PROBLEMS TO HEADQUARTERS. Bausch & Lomb offers: 1. America's largest precision optical facilities. 2. Ninety years of optical engineering. 3. An Optical Scientific Bureau. 4. Its own optical glass plant.



ARMY E NAVY

★★★★
ENLIST YOUR DOLLARS
Buy War Bonds

How Secret Weapons are Born

A brightly lighted laboratory window in a darkened building . . . a closely guarded door . . . by signs such as these you may recognize the hard-working scientists who are creating America's deadliest new fighting tools, through the O.S.R.D. (Office of Scientific Research and Development). Armed with the instruments which science knows best how to use, these selfless six thousand have already saved unnumbered lives, countless ships and planes.

They work in hundreds of laboratories throughout the country, laboratories which are equipped with the finest precision optical instruments. Their work is coordinated by a scientific high command, the O.S.R.D. They wear no uniforms nor medals, but work tirelessly for the triumph of Freedom.

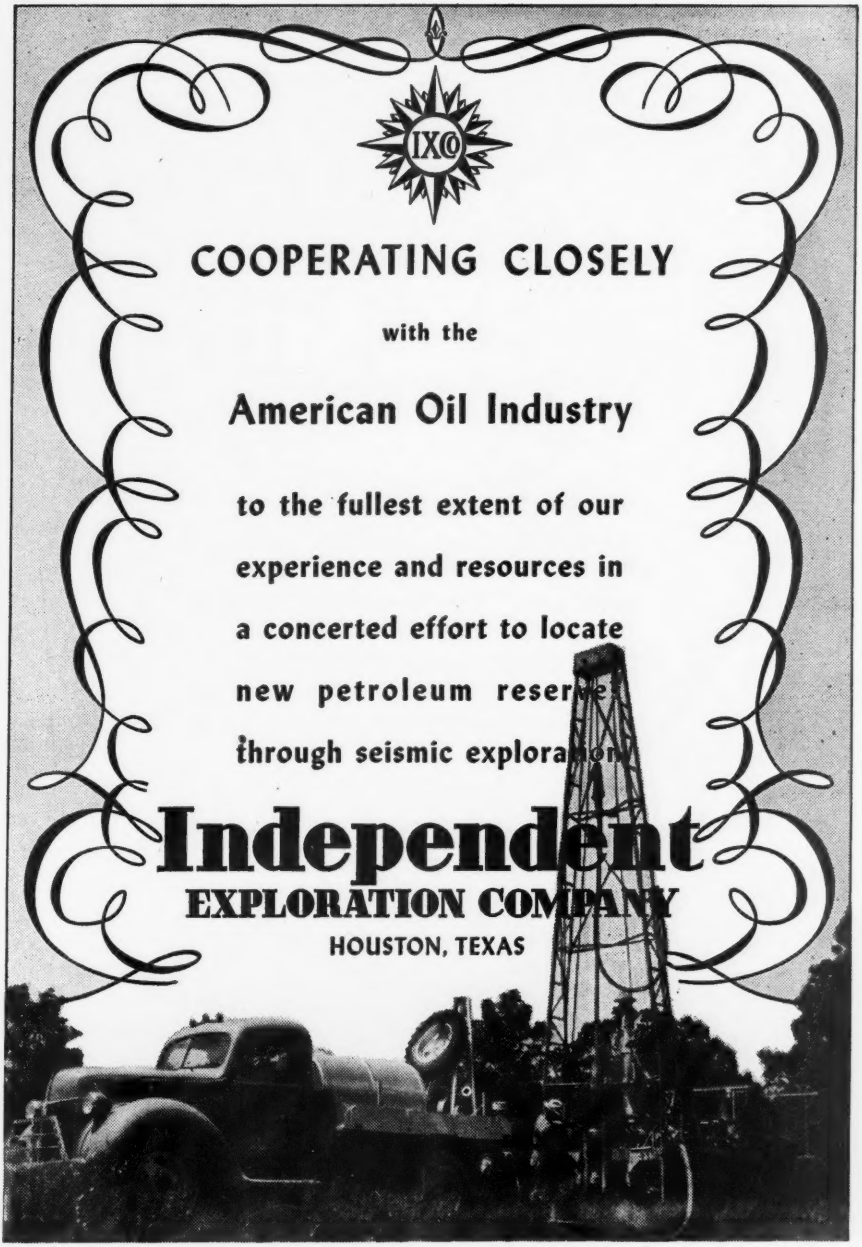
We are proud to be able to cooperate with the scientists working under O.S.R.D.; proud, too, of the part that our instruments have played in the furtherance of their efforts. In the able hands of these men the microscopes, spectrographs, metallographs, refractometers, projection equipment, and other specialized Bausch & Lomb instruments have become weapons of war . . . as important to the winning of battles as the range-finders, aerial camera lenses, binoculars, and other B&L military optical instruments.

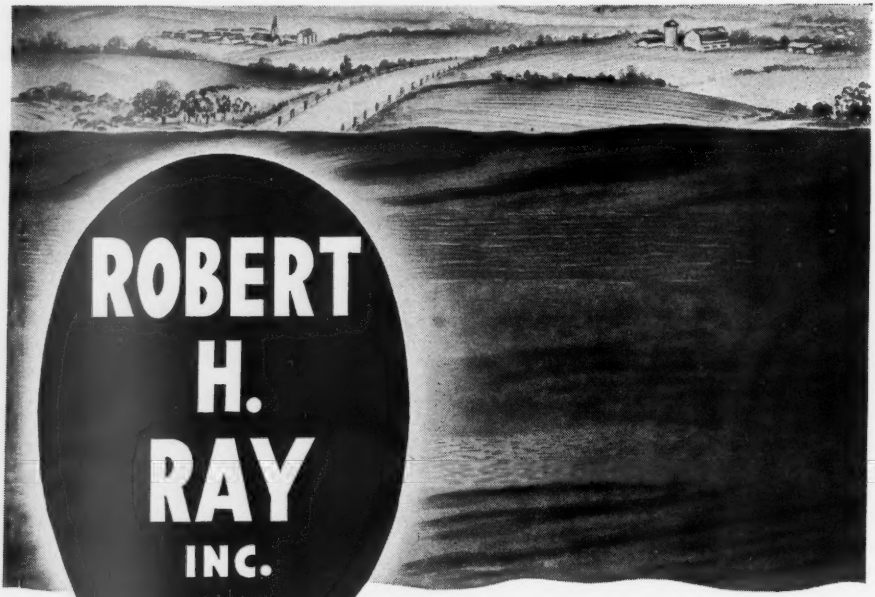
BAUSCH & LOMB

OPTICAL CO., ROCHESTER, N.Y.

EST. B&L 1853

Makers of Optical Glass and a Complete Line of Optical Instruments for Military Use, Education, Research, Industry and Eyesight Correction and Conservation


IXO
COOPERATING CLOSELY
with the
American Oil Industry
to the fullest extent of our
experience and resources in
a concerted effort to locate
new petroleum reserves
through seismic exploration
Independent
EXPLORATION COMPANY
HOUSTON, TEXAS

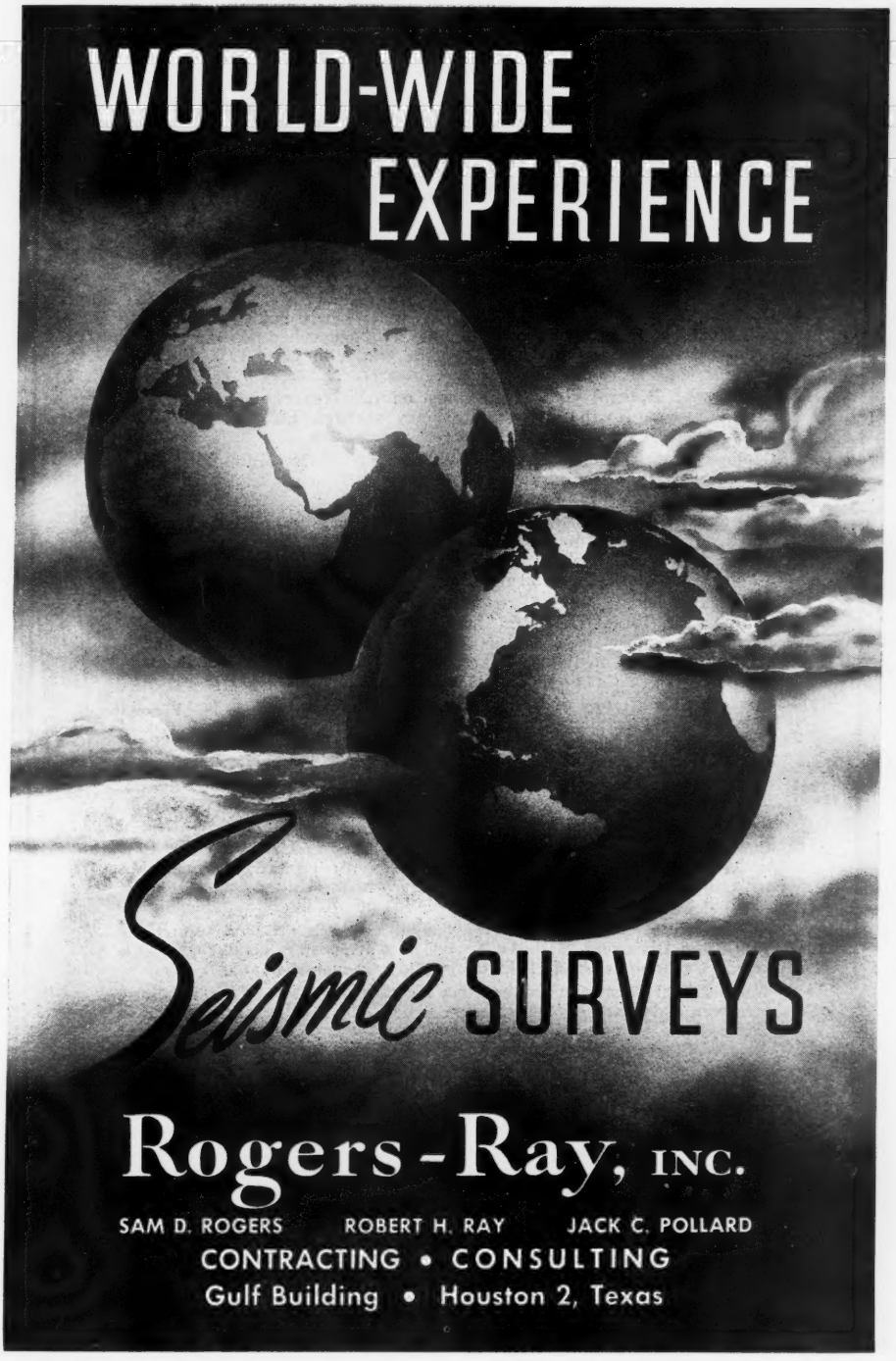


Geophysical Engineering
Gravity Surveys
Contracting • Consulting

FOREIGN
AND
DOMESTIC

ROBERT H. RAY JACK C. POLLARD

GULF BUILDING • • • • • HOUSTON, TEXAS


WORLD-WIDE
EXPERIENCE
Seismic SURVEYS
Rogers-Ray, INC.
SAM D. ROGERS ROBERT H. RAY JACK C. POLLARD
CONTRACTING • CONSULTING
Gulf Building • Houston 2, Texas

AVAILABLE PUBLICATIONS OF

The American Association of Petroleum Geologists

Box 979, Tulsa 1, Oklahoma

1931	**Geologic Map of Cuba.** Compiled by J. Whitney Lewis. Folded paper sheet, 24 x 10 inches. Scale, 3/16 inch = 10 miles. Geologic column on same sheet. From Lewis' "Geology of Cuba" (out of print), in June, 1932, *Bulletin.* Map per copy	$ .25
1935	**Geology of Natural Gas.** Symposium on occurrence and geology of natural gas in North America. By many authors. 1,227 pp., 250 illus. 6 x 9 inches. Cloth. **To members and associates, $4.50**	6.00
1936	**Geology of the Tampico Region, Mexico.** By John M. Muir. 280 pp., 15 half-tone plates, 41 line drawings, 9 tables. 6 x 9 inches. Cloth. **To members and associates, $3.50**	4.50
1936	**Gulf Coast Oil Fields.** Symposium on Gulf Coast Cenozoic. By 52 authors. Chiefly papers reprinted from the Association *Bulletin* of 1933-1936 gathered into one book. xxii and 1,070 pp., 292 figs., 19 half-tone pls. 6 x 9 inches. Cloth. **To members and associates, $3.00**	4.00
1936	**Areal and Tectonic Map of Southern California.** By R. D. Reed and J. S. Hollister. In 10 colors. From "Structural Evolution of Southern California," December, 1936, *Bulletin.* Scale, ⅛ inch = 1 mile. Map and 4 structure sections on strong ledger paper, 27 x 31 inches, rolled in mailing tube	.50
1938	**Miocene Stratigraphy of California.** By Robert M. Kleinpell. 450 pp.; 14 line drawings, including a large correlation chart; 22 full-tone plates of foraminifera; 18 tables (check lists and a range chart of 15 pages). 6 x 9 inches. Cloth. **To members and associates, $4.50**	5.00
1941	**Stratigraphic Type Oil Fields.** Symposium of 37 papers by 52 authors. 902 pp., 300 illus., 227 references in annotated bibliography. 6 x 9 inches. Cloth. **To members and associates, $4.50**	5.50
1942	**Source Beds of Petroleum.** By Parker D. Trask and H. Whitman Patnode. Report of investigation supported jointly by the American Petroleum Institute and the Geological Survey of the United States Department of the Interior from 1931 to 1941. 566 pp., 72 figs., 151 tables. 6 x 9 inches. Cloth. **To members and associates, $3.50**	4.50
1942	**Petroleum Discovery Methods.** Report of a symposium conducted by the research committee, April, 1942. 164 pp. 8½ x 11 inches. Paper	1.00
1942	**Map of West Texas and Southeastern New Mexico,** showing areal geology, structure, and oil and gas fields. Compiled by Philip B. King. 3 colors. 29 x 26 inches. Scale, 5/6 inch = 10 miles. **Correlation Chart of Permian System and Related Strata in West Texas Region.** By Philip B. King. 22 x 14 inches. From King's "Permian of West Texas and Southeastern New Mexico," in April, 1942, *Bulletin.* Folded paper sheets. Each, $0.25; both map and chart	.50
1944	**Possible Future Oil Provinces of the United States and Canada.** Symposium conducted by Association research committee. Reprinted and repaged from August, 1941, *Bulletin.* 154 pp., 83 figs. 6 x 9 inches. Paper. **To members and associates, $1.00**	1.50

Bulletin of The American Association of Petroleum Geologists. Official monthly publication. Each number, approximately 150 pages of articles, maps, discussions, reviews. Annual subscription, $15.00 (outside United States, $15.40). Descriptive price list of back numbers on request.

(Prices, postpaid. Write for discount to colleges and public libraries.)

An A.A.P.G. Book of Oil-Field Structure (1935)

Geology of Natural Gas

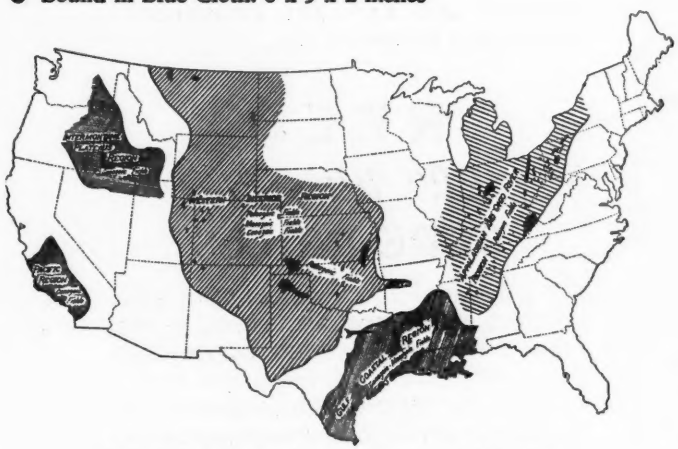
Edited by HENRY A. LEY

Here for the first time has been assembled a comprehensive geologic treatise of the occurrence of natural gas on the North American Continent.

- **1227 pages, including a carefully prepared index of 77 pages**
- **250 excellent illustrations, including Maps, Sections, Charts, Tables, Photographs**
- **Bound in Blue Cloth. 6 x 9 x 2 inches**

Articles on Fields in
Alberta
Ontario
Quebec
California
Washington
Idaho
Oregon
Utah
Montana
Wyoming
Colorado
New Mexico
Texas
Kansas
Oklahoma
Arkansas
Louisiana
Michigan
Illinois
Indiana
Kentucky
Ohio
Tennessee
Mississippi
Alabama
New York
Pennsylvania
West Virginia
Mexico

Valuation
Reserves
Helium
Rare Gases
The Industry



Reduced illustration showing natural gas regions in United States

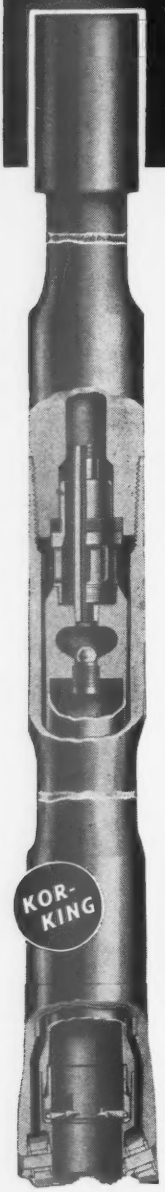
"There is scarcely any important fact relative to North American gas, be it stratigraphical, structural, or statistical, that cannot be readily obtained from the volume."—Romanes in *Jour. Inst. Petrol. Tech.* (London).

Price, postpaid, only $4.50 to paid-up members and associates, $6.00 to others

The American Association of Petroleum Geologists
BOX 979, TULSA, 1, OKLAHOMA, U.S.A.

A Complete

CORING SERVICE



REED

Kor-King

CONVENTIONAL TYPE

CORE DRILLS

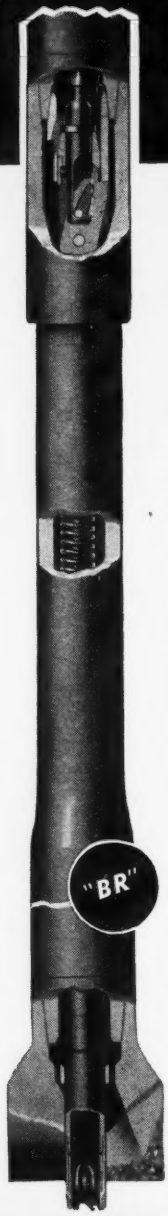
THE SLUSH LUBRICATED, OIL PROOF NEOPRENE BEARING IS A REED KOR-KING FEATURE, PERMITS THE USE OF A FULL FLOATING INNER BARREL, ELIMINATES BEARING TROUBLES AND ASSURES CONSISTENTLY DEPENDABLE PERFORMANCE.

REED

"BR" Wire Line

CORE DRILLS

FOR INTERMITTENT OR CONTINUOUS CORING. THE PROTRUSION REGULATOR SPRING PERMITS RETRACTION OF THE CUTTER HEAD INTO THE DRILLING BIT WHEN THE CUTTER HEAD IS FIRST SET ON BOTTOM AND ASSURES A HIGH PERCENTAGE OF UNCONTAMINATED CORE IN EITHER HARD OR SOFT FORMATIONS.

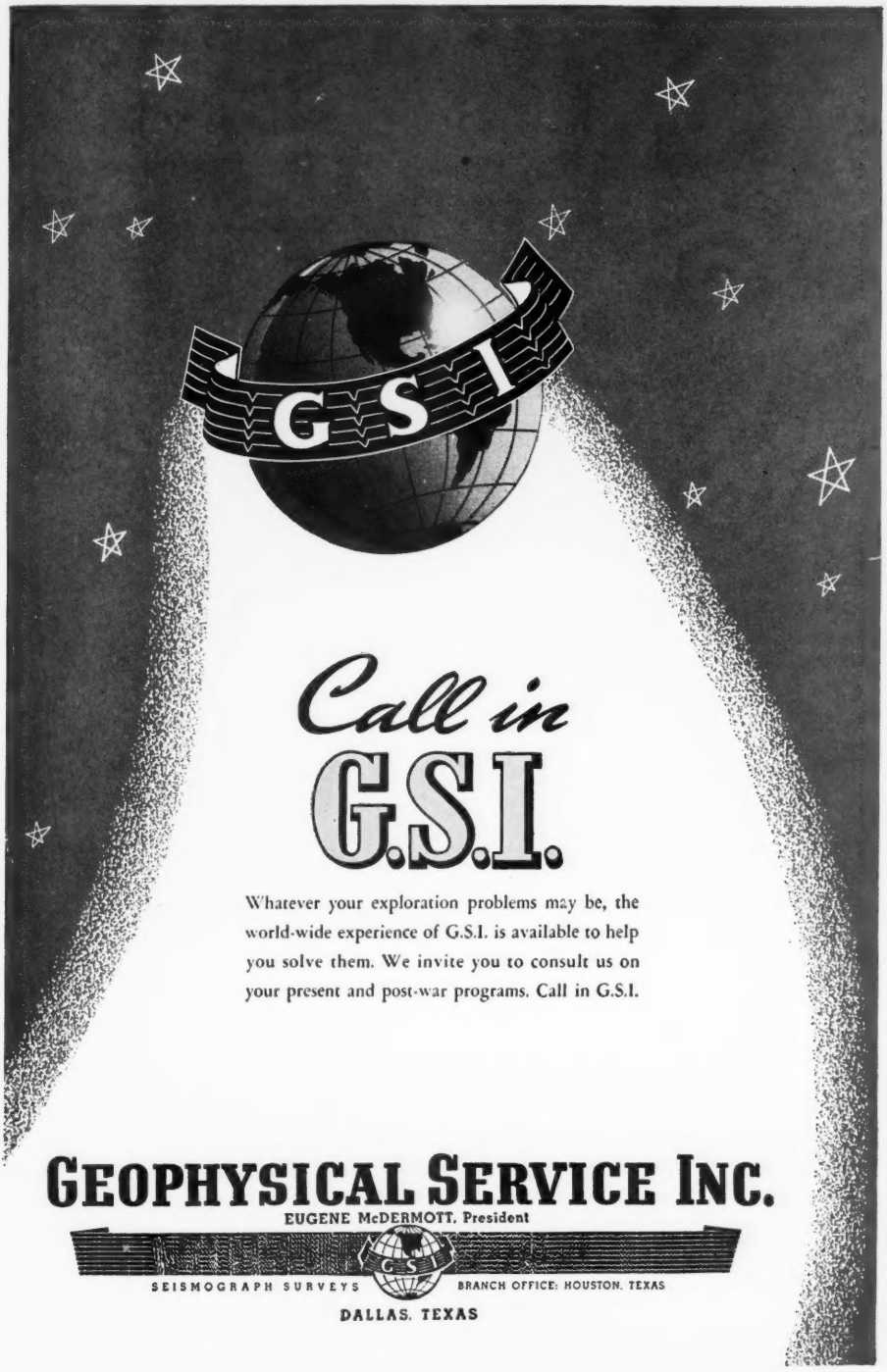


REED ROTARY DRILLING TOOLS

SPEED · ECONOMY · DURABILITY

REED ROLLER BIT COMPANY

P. O. BOX 2119 HOUSTON, TEXAS


G S I
Call in
G.S.I.
Whatever your exploration problems may be, the world-wide experience of G.S.I. is available to help you solve them. We invite you to consult us on your present and post-war programs. Call in G.S.I.
GEOPHYSICAL SERVICE INC.
EUGENE McDERMOTT, President
G S I
SEISMOGRAPH SURVEYS
BRANCH OFFICE: HOUSTON, TEXAS
DALLAS, TEXAS

OILING THE WAR

Victory—whether on the battlefront or the homefront—results from teamwork. In the Oil Industry, men and equipment are on the job 'round the clock, working together to provide the unprecedented quantities of petroleum products needed to *oil the war.*

Hughes Rock Bits, Core Bits, Tool Joints, and other specialized drilling tools are basic equipment in the production of oil, and are being manufactured in ever-increasing numbers to meet the needs of the Oil Well Drilling Industry.

HUGHES TOOL COMPANY HOUSTON, TEXAS